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Evaluation of a BMI Based Body Composition Equation in Intercollegiate Athletes

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ABSTRACT

INTRODUCTION: Assessment of body composition in collegiate athletes is an effective tool to enhance training and nutrition protocols. The use of Body Mass Index (BMI) based equations for such purposes has been found to be relatively invalid in athletes due to the inability to decipher between fat and fat-free mass. Recently, a BMI based equation developed by Nickerson et al. ($BMI_{NICKERSON}$) that incorporates handgrip strength as a surrogate for lean mass was found to estimate body fat with low error in general population adults. The use of such a method in collegiate athletes may in turn provide a cost-effective and easily administered option for body composition assessment. PURPOSE: To compare the effectiveness of $BMI_{NICKERSON}$ with traditional body composition methods in estimating body fat percentage of collegiate athletes. METHODS: Forty-one (n = 41) intercollegiate athletes (n = 21 male, 20 female) were assessed for percentage body fat using $BMI_{NICKERSON}$, bio-electrical impedance analysis (BIA) and seven site skinfold (SF). Pearson's correlation was utilized to assess relationships among measurements methods. A sex x measurement method Two-Way ANOVA with repeated measures on the latter was utilized to determine potential differences in body fat percentage as estimated by each method between males and females. RESULTS: Good to excellent agreement was displayed between BIA and $BMI_{NICKERSON}$ compared to SF in the total population and each sex ($r > 0.76$, $p < 0.001$). A significant interaction ($F = 5.01$, $p = 0.01$) between sex and measurement method was found for the sample. Paired samples t-testing in females revealed a significantly greater body fat estimation by $BMI_{NICKERSON}$ (26.75 % ± 3.72 %) in comparison to both BIA ($t = 7.73$, $p < 0.001$, 22.36 % ± 2.80 %) and SF ($t = 5.15$, $p < 0.001$, 23.37 % ± 4.49 %). BIA and SF did not significantly differ ($t = 1.51$, $p = 0.15$) in females. Further paired samples t-testing in males revealed a significantly greater body fat estimation by $BMI_{NICKERSON}$ (17.66 % ± 4.30 %) in comparison to both BIA ($t = 8.74$, $p < 0.001$, 13.15 % ± 4.28 %) and SF ($t = 8.78$, $p < 0.001$, 11.73 % ± 4.38 %). In addition, a significantly greater ($t = 2.10$, $p = 0.05$) body fat estimation was found using BIA in comparison to SF in males. CONCLUSION: Although the use of $BMI_{NICKERSON}$ in estimating body composition has been shown to provide relatively accurate results in the general population, the current study did not observe the same in collegiate athletes. Further research comparing $BMI_{NICKERSON}$ to a gold standard measurement technique in collegiate athletes is warranted.

INTRODUCTION

Body composition, comprised of fat mass and fat-free mass, is of interest to athletes in that peak performance can be manipulated to some extent based on alterations in body habitus. Depending on the particular sport, manipulations in overall body mass while maintaining an optimal level of lean mass can provide for advantageous competitive benefits (Thomas et al, 2016; Santos et al., 2014). Along with appropriate methods of nutrition and fitness training, utilizing valid and reliable methods to assess body composition can allow clinicians and athletes to better administer and tailor strategies to optimize performance (Hector & Phillips, 2018; Thomas et al., 2016). However, due to a variety of factors, including cost, the availability of such methods may vary based on the setting.

Anthropometric measurements are a basic and widely used method of assessing body composition and typically describe body mass, size, shape, and an estimation of adiposity. One such method includes Body Mass Index (BMI), calculated through body mass and stature, which has been a longstanding reliable and convenient tool (Garrow & Webster, 1985). As body size changes with general weight gain in sedentary populations, BMI theoretically can give the clinician a sufficient assessment of the overall adiposity gained by an individual. However, the appropriateness of using anthropometric measures is likely affected when lean mass is gained from fitness training and associated muscular hypertrophy, which can potentially make this measurement less valid when working with athletes in a performance setting (Nevill et al., 2006; Ode et al., 2007). More appropriate methods in the athletic population include techniques that can effectively differentiate between lean and fat mass.

A variety of more technical measurements exist to assess lean mass in athletes including dual energy X-ray absorptiometry (DXA) used to quantifying fat, lean, and bone tissues; under water weighing (UWW), which accounts for water displacement in terms of body density; and air displacement plethysmography (ADP) utilizing a Bod Pod to quantify body density using air displacement (Thomas et al, 2016). These methods have all been shown to be valid and reliable tools in measuring body composition in athletes, although the practicality of these methods varies (Kasper et al, 2021; Shim et al, 2014; Thomas et al, 2016). While the use of DXA, UWW, and ADP are typically more representative of a “gold standard” measurement for differentiating lean versus fat mass, such methods often require significant cost, physical space, and expertise to measure (Kasper et al., 2021). The availability of such techniques for assessing athletes in the strength and conditioning and/or field setting may therefore be impractical based on the resources at many intercollegiate institutions. The use of affordable methods may provide for more realistic assessment techniques in such settings, including skinfold measurements (SF) taken at various sites on the body to indicate subcutaneous fat and bioelectrical impedance analysis (BIA) that produces estimates of total body water by measuring the resistance of the body as a conductor to a very small alternating electrical current (Mijaraneds et al, 2013). While these may be more accessible to practitioners, the validity may not be as consistent in some populations (Burns et al., 2013; Mijdarends et al., 2013; Wheeler et al., 2013).

A variety of reasons exist for potential error when using time and cost-effective methods of body composition analysis, although this may be controlled through clinician experience and subject instructions. While technician expertise provides potential inaccuracies with SF, it has been a long standing and time effective method with relatively valid and reliable measurements with appropriate levels of experience (ACSM, 2021; Kasper et al., 2021). In comparison, handheld BIA provides a time effective measure, but has shown questionable validity in college-aged males and females despite controlling for potential error from hydration status (Rockmann et al., 2017). In all, studies comparing both SF and BIA to a criterion typically provide for potential variations up to 3.5% SEE with SF typically showing slightly more accurate results (Ackland et al., 2022). While prospective drawbacks exist, the notion of examining another cost-effective method of body composition assessment in athletes that may also limit estimation error is attractive for institutions where budget constraints exist.

While anthropometric assessments alone may not adequately account for fat versus lean mass, the correction of such measures using a strength assessment may be practical and cost efficient. Such a method was recently proposed and validated through an equation using handgrip strength to account for differences in muscle mass in addition to a simple BMI measurement (Nickerson et al., 2020). This equation, termed $BMI_{NICKERSON}$, was found to produce lower levels of error when compared to other BMI based body fat equations in general population adults (Nickerson et al., 2020). The use of this corrected BMI equation that accounts for lean mass through the use of a strength assessment may be intriguing as yet another cost-effective and portable technique for clinicians assessing athletes in the field. While this equation was found to be valid in a general population sample, it remains to be seen whether such a method may remain an advantageous tool when measuring athletes of whom typically require more precise results to tailor nutrition and training regimens to enhance performance.

Determining the best methods to measure body composition, more precisely the differentiation between fat and lean mass, in athletes persists as an important topic. While the aforementioned gold standard measures (i.e., DXA, UWW, ADP) undoubtedly provide for the most accurate results, such methods are not always available or practical in many settings. Therefore, the purpose of this study is to compare the $BMI_{NICKERSON}$ calculation to two established cost-effective and portable methods of body fat estimation in intercollegiate athletes: SF and BIA Through rigorous comparison of these methods, strength and conditioning professionals can help to better optimize the techniques available to them for assessment of intercollegiate athletes to in turn allow their clients to optimize performance.

METHODS

Subjects

Forty-one (n = 41) current NCAA Division II intercollegiate athletes (n = 21 male, 20 female) from a small midwestern university were included in the study. Exclusion criteria involved any individuals with injuries or anatomical abnormalities that would make the measurement techniques unable to be assessed or unsafe for the subjects. Descriptive characteristics of the subjects can be found in Table 1. All materials and protocols for the study were approved by the institutional Human Subjects Review Board.

Procedures

Subjects completed one visit to the laboratory. Subject preparation instructions to allow for accuracy of measurement were provided and described to each subject at least 24 hours prior to their research session. These instructions were as follows: (1) No strenuous exercise 24 hours prior to testing; (2) No alcohol consumption 48 hours prior to testing; (3) No use of diuretic agents (i.e. caffeine, chocolate, etc.) 12 hours prior to testing; (4) Maintain normal hydration status; (5) Do not eat within 1-2 hours of testing. Upon arriving at the lab, the purpose of the study and a description of the testing protocol was explained to each subject and an informed consent document was signed by each participant. Anthropometric and demographic information were collected via scale measurements and verbal discussion. Body fat percentage was then measured using three methods by an American College of Sports Medicine (ACSM) Clinical Exercise Physiologist in the following order: (1) handheld BIA, (2) SF measurement, and (3) handgrip dynamometry for inclusion in the $BMI_{NICKERSON}$ equation. Procedures for each method are detailed below.

Anthropometric and Demographic Information

Demographic information was obtained via verbal discussion. This information included name, age, sex, and sport. Height was measured to the nearest 0.1 cm and weight was measured to the nearest 0.1 kg with a balance beam scale/stadiometer (Health O Meter, Alsip, I). Body mass index (BMI) was calculated as follows:

$$BMI = \text{Weight in kg/height in } m^2$$

Measurements

Body Fat from Skinfold Assessment

Subjects were assessed using Lange Skinfold Calipers (Beta Technology, California, USA) and the seven-site formula for both males and females as described by the ACSM. SF is a valid and commonly used method for measuring body fat and is widely used in the health and exercise sciences (Thomas et al., 2016). This involves measurement using skinfold calipers to pinch a fold of skin and then measure the thickness in millimeters (mm) at seven anatomical areas in the following order: triceps, chest/pectoral, midaxillary, subscapular, abdomen suprailliac, and thigh. The general procedures as outlined by ACSM were utilized and then entered into a standard formula to determine body density. The sex-specific formula is described as follows (ACSM, 2021).

Males:

$$\text{Body Density} = 1.112 - 0.000043499 \text{ (sum of seven skinfolds)} + 0.00000055 \text{ (sum of seven skinfolds)}^2 - 0.00028826 \text{ (age)}$$

Females:

$$\text{Body Density} = 1.097 - 0.00046971 \text{ (sum of seven skinfolds)} + 0.00000056 \text{ (sum of seven skinfolds)}^2 - 0.00012828 \text{ (age)}$$

The body density value was then entered into the Siri equation for estimation of body fat as most commonly used and to stay consistent with the outlined ACSM recommendations (where Db = body density) (ACSM, 2021).

Fat Free Mass = [(4.95/Db) – 4.50] x 100

Body Fat from Handheld BIA

Subjects were assessed using handheld BIA. This is a commonly available method for measuring body fat and is widely used in the exercise sciences and strength and conditioning settings, although the validity is variable among differing subpopulations (Burns et al., 2013; Mijdarends et al., 2013; Wheeler et al., 2013). The particular device used was the Omron HBF-306C Fat Loss Monitor (Omron Healthcare, Inc, Illinois, USA). The procedure for the device is based on the physiologic rationale that muscle, blood vessels, and bones are body tissues having a high water content that conduct electricity easily. Body fat tissue has lower electrical conductivity (Wheeler et al., 2013). BIA as measured using the Omron device sends an extremely low-level electrical current of 50 kHz and 500 μA through the body to determine the amount of fat tissue.

The protocol for measurement using this particular BIA device entails entering of data for the patient including the "athlete" setting (instead of "normal"), height, weight, age, and sex. The monitor is then held in both hands using the associated electrode handles. A button is pressed to initiate the signal and a reading for Body Fat percentage is displayed within 5-10 seconds. In order to ensure appropriate hydration, the preparation instructions were provided as discussed previously.

Handgrip Dynamometry and $BMI_{NICKERSON}$ Calculation

The handgrip dynamometry test is a measure of static strength of the upper body and has been validated as a measure of strength in adults (ACSM, 2021). The instrument used for assessment was the Jamar Hydraulic Hand Dynamometer (Patterson Medical, Illinois, USA). The protocol for testing was based on ACSM guidelines (ACSM, 2021). The results from handgrip were then added to the following equation, along with BMI, to estimate body fat percentage using the $BMI_{NICKERSON}$ method (Nickerson et al., 2020):

Body Fat% = 21.504 – (12.484 x RHG) – (7.998 x gender) + (0.722 x BMI)

note: gender = 0 for females and 1 for males

RHG = Combined Hand Grip (kg) / Body Mass (kg)

Statistical Analysis

All statistical analyses were performed using the statistical package for the social sciences (SPSS, Version 28, Chicago, IL). A priori significance was set at $\alpha \leq 0.05$. Pearson's correlation was used to assess the relationship among body fat percentage as measured by SF and both BIA and $BMI_{NICKERSON}$. SF was used as the criterion due to superior validity and accuracy compared to BIA when measured against a gold standard in previous studies (Kasper et al., 2021; Rockmann et al., 2017). A sex by measurement method two-way ANOVA with repeated measures on the latter was utilized to determine potential differences in body fat percentage as assessed by each method between males and females. Paired samples t-testing was implemented to further evaluate a significant interaction between sex and measurement method. Descriptive statistics for males, females, and the entire sample are shown below in Table 1.

Correlation

Correlation analyses revealed significant positive associations and excellent agreement for both BIA and $BMI_{NICKERSON}$ compared to SF for the entire population. Additionally, significant positive associations and good agreement was found for both BIA and $BMI_{NICKERSON}$ compared to SF for both male and female subjects (see Table 2 for correlation statistics).

Table 1. Descriptive statistics of all measured data for males and females as assessed by BIA, SF, and $BMI_{NICKERSON}$ (Mean +/- SD).

	Age	**Height (cm)**	**Weight (kg)**	**BMI (kg/m²)**	**BIA (Body Fat %)**	**SF (Body Fat %)**	**$BMI_{NICKERSON}$ (Body Fat %)**
Male	19.61 ± 1.34	179.85 ± 7.60	83.39 ± 12.32	25.63 ± 3.11	13.15 ± 4.28	11.73 ± 4.38	17.66 ± 4.30
Female	19.80 ± 1.15	168.88 ± 7.32	67.55 ± 11.35	23.40 ± 3.30	22.36 ± 2.80	23.37 ± 4.49	26.75 ± 3.72
All Subjects	19.27 ± 1.24	174.75 ± 9.23	76.02 ± 14.21	24.59 ± 2.96	17.64 ± 5.88	17.41 ± 7.34	22.10 ± 6.08

Table 2. Pearson's correlation statistics for body fat % as estimated by BIA and $BMI_{NICKERSON}$ compared to SF. All correlations were significant at $p < 0.001$.

	SF and BIA	SF and $BMI_{NICKERSON}$
Males	$r = 0.78$*	$r = 0.76$*
Females	$r = 0.76$*	$r = 0.76$*
All Subjects	$r = 0.90$*	$r = 0.90$*

Comparison of Body Fat Percentage by Measurement Method

A significant interaction (F = 5.01, p = 0.01) between sex and measurement method was found for the entire sample.

Females

Paired samples t-testing in females revealed a significantly greater body fat estimation by $BMI_{NICKERSON}$ (26.75 % ± 3.72 %) in comparison to both BIA (t = 7.73, p < 0.001, 22.36 % ± 2.80 %) and SF (t = 5.15, p < 0.001, 23.37 % ± 4.49 %). BIA and SF did not significantly differ (t = 1.51,p = 0.15) in females (Figure 1).

Males

Paired samples t-testing in males revealed a significantly greater body fat estimation by $BMI_{NICKERSON}$ (17.66 % ± 4.30 %) in comparison to both BIA (t = 8.74, p < 0.001, 13.15 % ± 4.28 %) and SF (t = 8.78, p < 0.001, 11.73 % ± 4.38 %). In addition, a significantly greater (t = 2.10, p = 0.05) body fat estimation was found using BIA in comparison to SF in males (Figure 2).

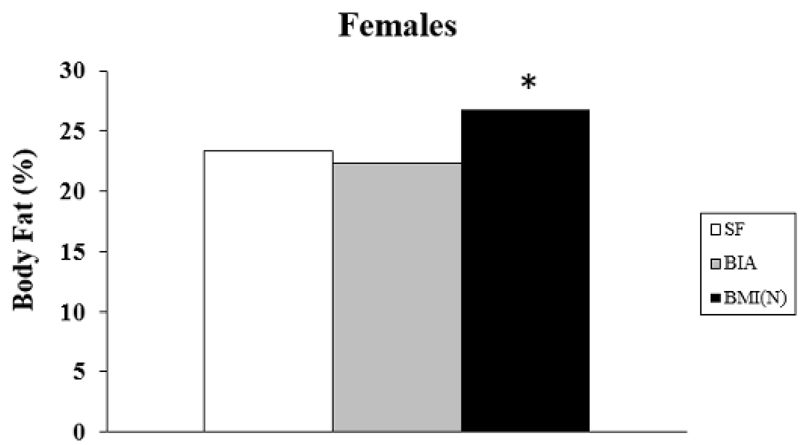

Figure 1. Mean body fat percentage for each measurement method in female athletes.
* Significant difference in body fat percentage compared to SF and BIA at p < 0.05.

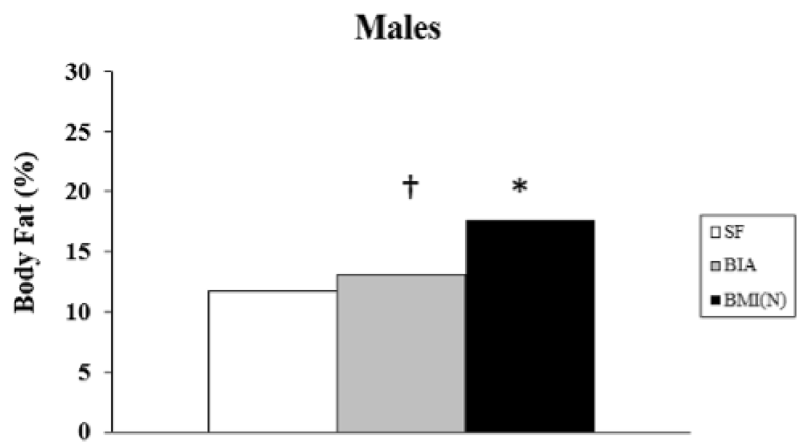

Figure 2. Mean body fat percentage for each measurement method in male athletes.
* Significant difference in body fat percentage compared to SF and BIA at p < 0.05.
† Significant difference in body fat percentage compared to SF at p < 0.05.05.

DISCUSSION

This is the first study to our knowledge to investigate the $BMI_{NICKERSON}$ equation in a sample of intercollegiate athletes (Nickerson et al., 2020). The main aim of the study was to compare the use of this newly developed assessment to comparable alternatives due to it's potential to be a quick and cost-effective method. Through the use of standard validation protocols via Pearson's correlation, the $BMI_{NICKERSON}$ equation showed good to excellent agreement with the well-established seven site SF method. In addition to the correlation analyses, mean comparison was utilized to determine the magnitude of differences in body fat percentage as assessed by each method. In the total population, and when the population was separated into categories by sex, $BMI_{NICKERSON}$ significantly overestimated body fat. This included overestimation of 4-5% in the total population, 3-4% in females, and 5-6% in males.

While good to excellent agreement was shown between measurement methods, the mean differences in body fat percentage estimation may be too great when considering an athletic population. In terms of ACSM normative tables, body fat percentage groups vary by approximately 3-4 % per category (i.e., very lean, excellent, good, etc.) making the margin for error seen in our study possibly change an athlete's classification by a full category (ACSM, 2021). This could lead to potential erroneous training and/or nutrition guidance based on estimations that are supposed to be assisting in such counselling.

The mean differences noted in our current sample of athletes are of particular importance when taking into account the relationship between body fat percentage and performance in a variety of athletes across a range of sports and demographics. Close correlation between body fat and a number of physical performance tests was found in youth soccer players in which it was concluded that such measures were predictive of potential athletic success (Esco et al., 2018). Similar findings were established in male adult recreational marathon runners in which body fat percentage was found to be strongly and positively correlated to running time (Tanda & Knechtle, 2013). Furthermore, the importance of body composition in relation to performance across a number of sports is echoed by respected bodies such as the ACSM in that carrying appropriate body fat percentage is necessary to optimize performance across a range of endurance (i.e. distance cycling) to strength and power (i.e. combat sports) events (Thomas et al., 2016). It is therefore apparent that athletes likely prefer and require more precise methods of assessment if such an indices is predictive of their performance.

The reason for potential variation among measurement techniques in our current study may be due to the specific sample of athletes measured. It is suggested that depending on the particular sport specialization of the athlete, grip strength may be enhanced by sport specific training and/or more predictive of percentage of lean mass underlying the mechanics of a grip strength test. For example, athletes participating in club, racquet, bat, and ball sports in which hand grip is regularly utilized may display a closer association between grip strength and muscle mass than other court or field sports (Cronin et al., 2017). Furthermore, other measures of fitness, including sprint speed, change of direction, and aerobic capacity have not been found to have a relationship to handgrip strength and seem to vary greatly based on the particular sport (Cronin et al., 2017). In our current sample, a variety of subjects were measured from sports including both grip and non-grip reliant athletes, potentially making handgrip a less appropriate surrogate for lean mass than in the general population utilized in the original $BMI_{NICKERSON}$ validity study (Nickerson et al., 2020). It would stand to reason that athletes in non-grip related sports may have a different distribution of lean mass than those in grip related sports, making hand grip strength an inaccurate representation of overall lean mass for some of the athletes studied. Furthermore, the opportunity to improve the use of hand grip strength as a representation of lean mass in athletes may be possible through investigations to determine how such a measure could be normalized in an athletic population. A recent study focused on normalization of grip strength based on simple body size dimensions in a sample of general population adults and determined that height had a significant relationship to grip strength. The results were then used to develop an equation to accurately normalize grip strength measurements by dividing by height squared (Nevill et al., 2022). This study displays that a need certainly exists to improve the accuracy of hand grip testing results and that such a technique has potential flaws as a surrogate for lean mass. Perhaps investigation into how body size correlates to strength may be utilized to normalize hand grip testing in an athletic population, and in turn develop a similar, easy to administer BMI calculation to estimate body fat such as seen with $BMI_{NICKERSON}$ in general population adults.

While the effect on performance creates the need for accurate and valid body composition testing methods, the overall health of the athlete makes this issue even more critical. Particularly in athletes who perform in events that involve weight classes (i.e., wrestling) or are heavily dependent on minimizing mass to optimize energy economy (i.e., distance running), low energy intake and drastic weight loss measures may foster an environment for dietary methods and psychological patterns similar to that seen in eating disorders (Sundgot-Borgen et al., 2013).While an initial benefit from weight loss may be felt by some athletes, the long-term performance, and overall health, may be compromised. It is suggested that such chronic low energy intake can potentially present reduced bone density, increase injury risk, and metabolic alterations (Melin et al., 2019). In addition, athletes who strive to improve performance by increasing weight through lean mass must pay close attention to percentage body fat. Such increases in lean mass require positive energy balance in addition to strength training and thus measurement of body fat is essential in avoiding the potential for fat mass gains that are present while maintaining a positive caloric balance (Garthe et al., 2013). The use of appropriate screening, prevention, and treatment measures therefore are highly recommended by multiple outlets in order to minimize the overall negative health outcomes and effects on performance in which athletes in weight dependent sports may face (Garthe et al, 2013; Melin et al., 2019; Sundgot-Borgen et al., 2013). It is apparent that accurate body composition analysis in such athletes be an integral part of such a strategic plan, which makes minimizing the error of estimation paramount.

LIMITATIONS/FUTURE RECOMMENDATIONS

While this is the first study to examine the use of $BMI_{NICKERSON}$ in an athletic population, it is not without limitations. The sample size was relatively small and could benefit from not only an increase in size, but also an increase in diversity. The current study evaluated subjects from a small university in the Midwest of the United States providing for a mostly middle class and Caucasian sample. Future research could benefit from the use of a more diverse athlete sample in a variety of socioeconomic settings. Furthermore, there was a lack of access to a gold standard body composition assessment method (i.e., DXA) during the current study. A similar study design using the $BMI_{NICKERSON}$ calculation may lend itself to a more robust validity study. In addition to the noted limitations, future research studies branching from the current protocol could be beneficial to the knowledge base of athlete body composition assessment. A comparison of sport-specific differences in the accuracy of $BMI_{NICKERSON}$ could be implemented, particularly comparing athletes in grip related and non-grip related sports. In addition, an investigation into hand grip normalization techniques in athletes using body size dimensions may aid in development of a BMI based body fat estimation equation that would be more representative of lean mass and more sensitive to body fat percentage estimation in the current population.

CONCLUSION

Although the use of $BMI_{NICKERSON}$ in estimating body composition has been shown to provide relatively accurate results in the general population, the current study did not observe the same in intercollegiate athletes. Based on previous research and the current study outcomes, institutions requiring cost-effective methods of body composition assessment may be best served by utilizing SF measurement performed by a well-trained clinician to estimate body fat. Further research comparing $BMI_{NICKERSON}$ to a gold standard measurement technique in intercollegiate athletes is warranted. This research may also include an examination of individuals from various racial, ethic, and sport backgrounds in addition to a variety of body fat categories.

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