5-2015

Validity and Reliability of A-Mode Ultrasound for Body Composition Assessment of Lean, Division I Athletes

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VALIDITY AND RELIABILITY OF A-MODE UNLTRASOUND FOR BODY COMPOSITION ASSESSMENT OF LEAN, DIVISION I ATHLETES

By

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A Plan B Paper submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

In Health & Human Movement

Approved:

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UTAH STATE UNIVERSITY
Logan, Utah

2015

INTRODUCTION

Athletes strive for a competitive advantage, and for some athletes building a lean body with a low body fat percentage (%BF) can help them achieve a higher level of performance. This is particularly the case in gravitational sports in which a high body mass hinders performance, in aesthetic sports in which there is a perceived ideal shape, and in weight class sports in which competition is organized into categories of body mass (20). However, some athletes put themselves at risk of health problems through extreme dieting, disordered eating, and fluid restriction in an effort to achieve a particular weight or %BF (20). Whether it be tracking fat loss results or monitoring healthy habits, body composition assessment can serve as a beneficial tool for both coaches and athletes to help the athlete achieve a reasonable and healthy competitive weight.

Various body composition testing methods are used in sports medicine. The most commonly used criterion or reference methods that offer the most precision include dual-energy X-ray absorptiometry (DXA), hydrodensitometry, and air displacement plethysmography (ADP), more commonly known as the Bod Pod (25). However, these large laboratory devices are expensive, not always practical, and in the case of DXA require specialized personnel or training to operate. Small, portable field methods such as bioelectrical impedance (BIA) and skinfolds offer more flexibility of measurement and could be advantageous when measuring athletes at event-site locations. However, the precision of these field methods is not at the same level as the reference methods (25).

A possible alternative that is small enough to be a portable field method yet potentially as accurate as the laboratory methods is ultrasound. The technical principles of this method as well as the strengths and limitations of ultrasound to provide reliable and valid body composition assessments were recently reviewed (23). The review concluded that ultrasound has great potential to provide reliable and accurate estimates of subcutaneous fat, but more research is needed specific to new devices and software that were designed specifically for the purpose of body composition assessment. Additionally, an Ad Hoc Working Group on Body Composition, Health and Performance of the International Olympic Committee Medical Commission recently suggested that ultrasound and the emerging software and technological advances of this method might offer advantages over other methods for assessing the body composition of Olympic athletes (15). This research team developed software that can accurately assess subcutaneous adipose tissue to within 0.1 to 0.5 mm of thickness (14). However, the software is meant to be used with a high-resolution B-mode ultrasound unit. These medical devices are costly (typically > $10,000), and the software is > $2,000.

A novel and relatively inexpensive (< $2,000) A-mode ultrasound device (BodyMetrix BX2000), with user-friendly body composition-specific software, is now commercially available. This device was mentioned in Wagner's (23) review of ultrasound for body composition assessment, and it was noted that there is still relatively little published research regarding its validity. If found to be accurate, it would provide a lower cost alternative to the B-mode ultrasound suggested by Müller et al. (14) for assessing the body composition of elite athletes, and greater portability than the laboratory methods. Thus, the purpose of this study was to test the validity, test-retest reliability, and inter-rater reliability of the BX2000 A-mode ultrasound by comparing it to skinfolds and the Bod Pod in a sample of lean, Division-I collegiate athletes.

METHODS

Experimental Approach to the Problem

This was a repeated measures design such that all athletes in the study had their body composition assessed by all three methods. Additionally, the same two experienced technicians took all of the skinfold and ultrasound measurements in duplicate in order to evaluate test-retest reliability and inter-rater reliability.

Subjects

Forty-five (22 males, 23 females) National Collegiate Athletic Association (NCAA) Division-I athletes were recruited to participate in this study. The descriptive statistics are represented in Table 1. The student-athletes were from 7 different sports: football (n = 8), golf (n = 7), women's gymnastics (n = 9), softball (n = 4), women's volleyball (n = 1), and men's (n = 7) and women's tennis (n = 9). It should be noted that lean athletes were the focus of this study, and only those who the researchers thought would be below 18% BF for males and 30% BF for females were invited to participate. All participants signed an informed consent form that was approved by the university's institutional review board.

[*Table 1. About here*]

Procedures

Preliminary procedures

Following informed consent and prior to body composition testing, participants were asked to void their bladder and bowels. Height was measured to the nearest 1 mm using a wall-mounted stadiometer (Seca 216, Seca Corp., Ontario, CA). Weight was measured to the nearest 0.01 g during the Bod Pod procedure. The Bod Pod (Cosmed USA, Inc., Concord, CA) was calibrated following the manufacturer's guidelines, and the precision of the skinfold caliper (Lange, Cambridge Scientific Industries, Inc., Cambridge, MD) was checked against 15 mm and 25 mm calibration blocks.

Bod Pod

Participants were measured while wearing tight-fitting clothing (e.g., lycra swimsuit or compression clothing) according to standardized procedures (5), and manufacturer's guidelines were followed for the Bod Pod assessment. Thoracic gas volume (TGV) was measured to attain the highest degree of precision possible with the Bod Pod measurement. Body density (Db) was converted to %BF using the conversion formula of Siri (18). The same technician performed all of the Bod Pod tests.

Skinfold

Following the Bod Pod assessment, participants underwent the skinfold and ultrasound assessments. The Jackson and Pollock 3-site skinfold locations and equations (6,7) were used to estimate %BF. The sites included the chest, abdomen, and thigh for males (6), and the triceps, suprailiac, and thigh for females (7). The same sites were used for the ultrasound measurements.

The sites were marked using a surgical marker to maintain consistency for the ultrasound measurements. Standardized procedures for the skinfold technique as described by Heyward and Wagner (5) were followed. Two technicians performed the measurements in duplicate. They were blinded to each other's readings. Again, the Siri (18) formula was used to covert the skinfold-derived Db to %BF.

Ultrasound

The BodyMetrix BX2000 (IntelaMetrix, Inc., Livermore, CA) A-mode ultrasound in conjunction with the associated Body View software was used to make the ultrasound measurements. The manufacturer's recommendations for making single-point ultrasound measurements at the previously mentioned skinfold sites were followed. This included placing conducting gel on both the ultrasound transducer head and the measurement site on the participant to minimize friction and allow the transducer to freely move on the participant's skin. The transducer was then moved back and forth about a quarter inch (0.64 cm) to either side of the measurement site for about 3 seconds. Care was taken to minimize the pressure applied to the transducer head so as not to compress the skin, thereby altering the subcutaneous fat thickness. Subcutaneous adipose tissue thickness was recorded at each measurement site, and the %BF was automatically calculated from the Body View software. The same technicians that performed the skinfold measurements also took the ultrasound measurements, again being blinded to the other's readings.

Statistical Analyses

All data were analyzed using SPSS version 22 (IBM, Inc., Armonk, NY). Statistical significance was accepted at $p < 0.05$. Means and standard deviations were calculated for all variables, and normality was assessed with the Shapiro-Wilk test. Both the test-retest reliability and inter-rater reliability of %BF estimated from skinfolds and ultrasound were assessed with intraclass correlation (*ICC*) with a two-way mixed model and absolute agreement. Additionally, as recommended by Weir (26), the standard error of measurement [$SEM = SD\sqrt{(1\text{-}ICC)}$] was calculated in order to obtain the minimal difference ($MD = SEM \times 1.96 \times \sqrt{2}$) for the test-retest reliability of the skinfold and ultrasound methods. The *MD* is of interest because values that exceed the *MD* when doing repeat measurements, in weight change studies for example, are considered to be "real" change that exceeds the error of measurement (26). The relationship between skinfold thickness and uncompressed subcutaneous adipose tissue thickness from ultrasound at each of the measured sites was evaluated with Pearson correlation. A one-way repeated measures analysis of variance (ANOVA) was used to compare mean differences between the %BF estimates of the 3 assessments (Bod Pod v skinfold v ultrasound) with sex as a covariate, and Sidak post-hoc was used to further elucidate the differences from the ANOVA. Other validity criteria were also used such as evaluating the magnitude of the standard estimation of error (*SEE*) and total error (*TE*) as described by Heyward and Wagner (5). Bland-Altman (3) plots were also used to evaluate individual differences rather than only mean differences.

RESULTS

Twelve of the 45 subjects were unable to get a valid measured TGV even after 5 attempts; thus their predicted TGV was used. Research suggests that the difference in predicted TGV is not significantly different from measured TGV for the majority of athletes (25).

Assumptions were tested on Bod Pod data before the repeated-measures ANOVA was run. There were no outliers, and data were normally distributed (Shapiro-Wilk $p = 0.31$). Mauchly's test of sphericity was significant ($p < 0.01$), so the Greenhouse-Geisser method was used to evaluate the within-subject effects.

The test-retest *ICC* for skinfold and ultrasound for technician 1 was 0.999 (95% CI = 0.999 – 1.000) and 0.996 (95% CI = 0.993 – 0.998), respectively. Similarly, for technician 2 the *ICC* was 0.996 (95% CI = 0.993 – 0.998) for skinfold and 0.993 (95% CI = 0.987 – 0.996) for ultrasound. The *MDs* for the skinfold method were 0.7% BF and 1.5% BF for technician 1 and 2, respectively. The *MD* for the ultrasound method ranged from 1.3% BF for technician 1 to 1.8% BF for technician 2. The inter-rater *ICC* for skinfold was 0.966, but with a large 95% CI of 0.328 to 0.991. The inter-rater *ICC* for ultrasound was 0.987, but with a much smaller 95% CI of 0.976 to 0.993.

The skinfold and subcutaneous fat from the ultrasound were highly correlated at each of the measurement sites ($r > 0.68$, $p < 0.01$) with one exception. Also, with the exception of the suprailiac site, the correlations for technician 1 were slightly higher than for technician 2. The skinfold-ultrasound correlation for each site from both technicians can be found in Table 2.

[*Table 2. About here*]

The results for the ANOVA indicated a statistically significant difference between body composition methods, $F = 13.24$, $p < 0.01$, $\eta^2 = 0.24$. The interaction of body composition method with sex was also significant ($F = 14.68$, $p < 0.01$, $\eta^2 = 0.25$). Inspection of this data show that there is reasonably good agreement across technicians and methods for the male athletes, but not for females. Mean %BF data for the three methods are in Table 3.

[*Table 3. About here*]

The Sidak post-hoc analysis revealed that the two skinfold trials of technician 1 were similar to each other ($p = 1.00$) and not significantly different than the Bod Pod ($p = 0.50$ and 0.62 for trial 1 and 2, respectively). However, these three measurements (technician 1's two skinfold trials and the Bod Pod) were significantly less than the %BF estimation from technician 2's skinfolds and all of the ultrasound measurements ($p < 0.01$). There was no difference between the two technicians for the ultrasound ($p = 0.92$ to $p = 1.00$). Technician 2's skinfolds were similar to each other ($p = 1.00$) and nearly identical to his ultrasound measurements ($p = 1.00$).

All four of the %BF estimates from the ultrasound were similar and not significantly different; thus they were averaged and compared to the %BF estimate from the Bod Pod (Figure 1). Linear regression using the %BF estimate from ultrasound to predict %BF from the Bod Pod resulted in an $R^2 = 0.849$, $SEE = 2.6\%$ BF and a $TE = 4.4\%$ BF. Finally, the Bland-Altman plot depicting individual errors for %BF estimated from ultrasound compared to the Bod Pod is presented in Figure 2.

[*Figure 1. About here*]

[*Figure 2. About here*]

DISCUSSION

The purpose of this study was to test the validity and reliability of the BX2000 A-mode ultrasound for estimating %BF in lean athletes by comparing it to skinfolds and the Bod Pod. First, both the ultrasound and skinfolds had very high test-retest reliability which means both technicians were consistent with themselves. Anders et al. (1) recently reported test-retest *ICC*s ranging from 0.88 to 0.98 for %BF estimated from a variety of skinfold equations in a sample of military personnel. Despite high *ICC*s, they noted that six out of seven skinfold site measurements were significantly higher on the retest and that the limits of agreement were slightly wider for the skinfold method than bioelectrical impedance. For the BX-2000 ultrasound, Smith-Ryan (19) reported an *ICC* of 0.98 and *MD* of 4.3% BF for a seven-site measurement, and Loenneke et al. (10) reported an *ICC* of 0.94 with an *MD* of 5.8% BF using the same three measurement sites performed in the present study. In contrast, the *MD*s for both technicians in the present study were < 2% BF for both the skinfold and ultrasound methods. Some potential reasons for superior test-retest reliability values for our study could be a leaner sample and a shorter time period between the first and second measurement. Our study sample consisted of lean athletes but Smith-Ryan et al. (19) measured overweight and obese adults. Both Loenneke et al. (10) and Smith-Ryan et al. (19) took their retest measurements on a different day (day-to-day reliability), whereas our repeat measurement was taken immediately after the first measurement. Furthermore, we marked our measurement locations which likely improved the reliability (5).

To the best of our knowledge, this is the first study to examine the inter-rater reliability of this A-mode ultrasound device for estimating %BF. The inter-rater *ICC*s were very large for both the skinfold and ultrasound methods; however, the 95% CI was very large for skinfolds and very narrow for ultrasound. This indicates that for the skinfold method the technicians were consistently inconsistent with technician 1 consistently recording lower skinfold measurements then technician 2. Previous researchers have also commented on the difficulty of obtaining high inter-rater reliability using the skinfold method (9,12). Kispert and Merrifield (9) examined the inter-rater reliability of skinfolds by comparing the results of eight different raters who each measured three anatomical sites on 20 subjects. They concluded that the inter-rater reliability using the skinfold technique was insufficient for tracking body fat measurements. In the present study, the post-hoc analysis from the ANOVA confirmed a significant technician difference for skinfolds but no difference for the ultrasound measurements. On average, the two technicians' skinfold measurements differed by about 1.9% BF on the male athletes and 3.3% BF on the female athletes (Table 3). In contrast, they differed by only about 0.2% BF when using the ultrasound method, regardless of sex being tested (Table 3).

We also considered the relationship between skinfold and ultrasound at the individual measurement sites (Table 2). Ulbricht et al. (21) pointed out that the values for skinfold were greater than the values for ultrasound at any given site in their sample of military personnel. This is to be expected because a skinfold involves a double layer of skin along with the compressed fold of subcutaneous fat (5), whereas the ultrasound method is directly measuring the subcutaneous fat thickness (23). Despite the difference in absolute value, it is logical to assume a high correlation between methods because they are both measuring subcutaneous fat. Surprisingly, Ulbricht et al. (21) reported weak, non-significant correlations between skinfold and ultrasound for about half of the nine sites that they measured. In contrast, correlation coefficients were > 0.80 at nearly every site for both sexes as measured by both technicians (Table 2). We cannot explain the low correlations reported by Ulbricht et al. (21); however, the fact that the anatomical locations remained marked between the skinfold and ultrasound measurements likely contributed to our high correlations.

Regarding validity, there was a significant difference in the %BF estimates from the three methods such that the mean %BF from the Bod Pod was about 3% lower than the mean %BF from the ultrasound, with the skinfold estimate of technician 1 matching closely to the Bod Pod and the skinfold estimate of technician 2 matching closely to the ultrasound (Table 3). Assuming that the Bod Pod is a valid criterion measure, the *SEE* of ultrasound was near the excellent category but the *TE* was only fair according to the subjective evaluative ratings reported by Lohman (11). Upon closer inspection, sex was an important covariate. When only males were considered in the analysis, all differences to the Bod Pod became non-significant, and both the skinfold and ultrasound methods were within ± 1.5% BF of the Bod Pod. Additionally, the *TE* was reduced to 2.8% BF, a very good rating (11). However, the Bod Pod produced significantly lower %BF values than either the skinfolds or the ultrasound for females, and these were large mean differences ranging from 3.0% BF to 5.1% BF. Furthermore, the *TE* grew to 5.5% BF for the female only sample. In summary, There was good agreement between all three methods for the male athletes, but both the skinfold and ultrasound methods produced substantially higher %BF estimations than the Bod Pod for female athletes.

Several other research teams have also done validity studies using portable A-mode ultrasound to estimate %BF with variable results. Pineau and colleagues (17) used a combination of anthropometric dimensions and ultrasound measurements at the abdomen and mid-thigh to develop a new model to predict fat mass in 89 adults ranging in age from 18-60 y. They evaluated this against DXA, ADP, and BIA. The ultrasound estimates of %BF provided higher correlations to the DXA measurement than the ADP or BIA methods. The 95% limit of agreement was also narrower for ultrasound than ADP and BIA. This research team repeated their ultrasound model on a sample of 93 athletes (16). They reported very high correlations to DXA for both males ($r = 0.98$) and females ($r = 0.97$) and an excellent 95% limit of agreement of -0.06 ± 1.2% BF. It should be noted that the research of Pineau et al. (16,17) used a different ultrasound device and prediction model than the BodyMetrix BX2000 and Jackson et al. formulas (6,7) used in the present study. However, other researchers have used the BX2000 in their validity studies (8,10,19,21,22). Compared to skinfolds, Loenneke et al. (10) reported no significant difference but high *TE* in a small, mixed-sex group of college students, and Ulbricht et al (21) reported no significant difference in the %BF estimation of 60 male military personnel despite some low correlations at the individual measurement sites. Recently, Smith-Ryan et al. (19) compared BX2000-estimated %BF using the 7-site Jackson and Pollock equation with a three compartment model that used the Bod Pod to obtain Db and BIA to estimate total body water in a group of 47 overweight and obese adults. They found that, despite good reliability, the ultrasound significantly underestimated the %BF. In contrast, in a sample of 26 college students, Johnson et al. (8) reported significant correlations ($r \geq 0.86$) and no significant differences between %BF estimates from the BX2000, ADP, and BIA. Finally, in a study of 70 euhydrated high school wrestlers, Utter and Hager (22) found excellent agreement between ultrasound and hydrodensitometry for the estimation of fat-free mass while skinfold significantly underpredicted this variable. Additionally, the *SEE* was less for ultrasound than skinfold, and these researchers concluded that ultrasound should be considered as an alternative method for estimating the fat-free mass of wrestlers.

There are several additional points to consider in the evaluation of the BodyMetrix BX2000 ultrasound. This is the first study to include more than 8 lean or average weight females. Smith-Ryan et al. (19) included 27 females in their study, but these were overweight and obese women. They found that the ultrasound method significantly underestimated %BF compared to a three component model, while we found a severe overestimation for lean females compared to the Bod Pod. Also, while realizing that there is no true “gold standard” of body composition assessment, we assume that the Bod Pod is a valid criterion method for this sample. Previous researchers have concluded that the Bod Pod is a valid method for measuring %BF in female collegiate athletes (2, 13).

In summary, the BodyMetric BX2000 ultrasound device had excellent test-retest reliability as well as inter-rater reliability. The inter-rater reliability of the ultrasound was superior to the skinfold method. Overall, the ultrasound overpredicted %BF of collegiate athletes. However, this overprediction was more pronounced in the female athletes and of little practical significance in the male athletes. More research is warranted on this device, particularly given the paucity of research that includes large samples of female participants. Nevertheless, regardless of its questionable validity, given the excellent reliability, portability, and ease of use, A-mode ultrasound has promise as a method to assess change in %BF.

PRACTICAL APPLICATIONS

Whether it be tracking fat loss results, muscle mass gains, or estimating ideal competitive weight, body composition assessment can serve as a beneficial tool for both coaches and athletes. Not every institution has the resources available for a laboratory method such as the Bod Pod; thus, more convenient and less expensive options like the skinfold method are typically used. However, as illustrated in the current study, the inter-rater error of even experienced skinfold technicians can be substantial. When multiple observers, such as various strength coaches and athletic trainers, with varying levels of skill and experience are involved in assessments using skinfolds the inter-rater reliability will likely be poor. The ultrasound technique proved to have much higher inter-rater reliability than the skinfolds, making it more likely for multiple examiners to get similar results. More research is needed before this method can be recommended as a valid assessment of %BF in female athletes; however, our results combined with those of Utter and Hager (22) on high school wrestlers suggest that ultrasound is a valid alternative for estimating the %BF of male athletes. Regardless of its validity, we echo the sentiments of others who suggested that this device may be an effective tool for tracking changes in body composition due to its excellent reliability (10, 19). Combine this finding with the relatively inexpensive cost and ease of use, and the A-mode ultrasound could be a viable alternative for strength coaches and athletic trainers seeking to assess the body composition of their athletes.

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Figure Legend

Figure 1. Relationship between body fat percentage (%BF) estimated from ultrasound and %BF estimated from the Bod Pod. Solid line represents the line of identity and dashed line is the regression line.

Figure 2. Bland-Altman analysis of the residual scores. Solid line is the constant error and the dashed lines are ± 2 SD.

Figure 1.

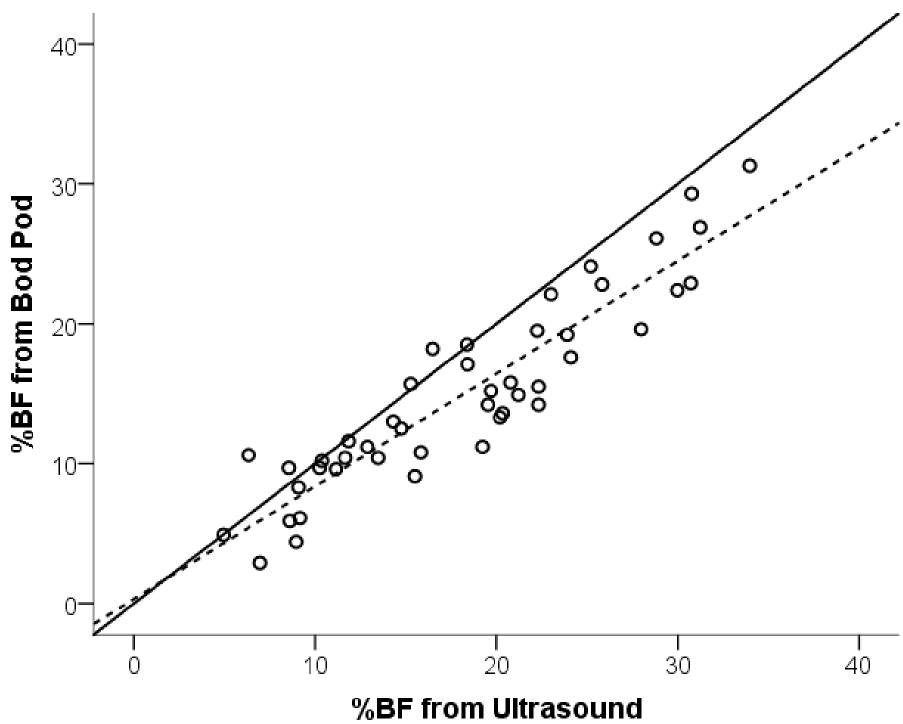

Figure 2.

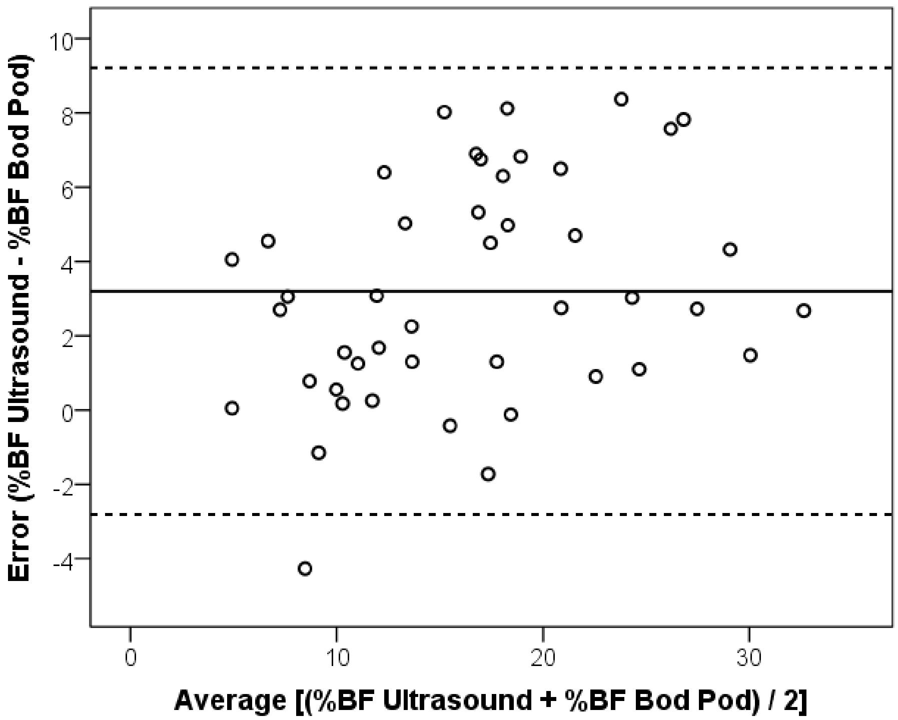
Error (%BF Ultrasound - %BF Bod Pod)
10
8
6
4
2
0
-2
-4
0
10
20
30
Average [(%BF Ultrasound + %BF Bod Pod) / 2]

Table 1. Descriptive statistics (mean ± SD).

	Total (*N* = 45)	**Male (*n* = 22)**	**Female (*n* = 23)**
Age (y)	20.1 ± 1.6	20.6 ± 1.6	19.6 ± 1.4
Height (cm)	172.2 ± 10.2	179.8 ± 6.5	165.0 ± 7.3
Weight (kg)	71.8 ± 12.4	80.8 ± 10.7	63.3 ± 6.6
BMI (kg/m²)	24.1 ± 2.4	24.9 ± 2.4	23.3 ± 2.2

Table 2. Correlation between skinfolds and ultrasound at each measurement site.

	Males (n = 22)						Females (n = 23)					
	Chest		Abdomen		Thigh		Triceps		Suprailiac		Thigh	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Tester 1	.809	.847	.817	.776	.938	.943	.854	.824	.786	.840	.745	.897
Tester 2	.801	.731	.810	.798	.866	.920	.820	.687	.822	.906	.402[a]	.769

Note: $p < 0.01$ for all correlations; [a]$p > 0.05$

Table 3. Body fat percentages (%BF) from the three methods (mean ± SD).

	Skinfold	Ultrasound	Bod Pod
Technician 1; Trial 1	15.9 ± 8.1	18.2 ± 7.6	14.9 ± 6.7
	male: 8.9 ± 3.2	male: 11.7 ± 3.4	male: 10.1 ± 3.9
	female: 22.6 ± 5.0	female: 24.3 ± 4.7	female: 19.6 ± 5.5
Technician 1; Trial 2	15.8 ± 8.2	18.3 ± 7.9	
	male: 8.8 ± 3.2	male: 11.7 ± 3.6	
	female: 22.6 ± 5.2	female: 24.7 ± 5.0	
Technician 2; Trial 1	18.5 ± 8.7	18.1 ± 7.7	
	male: 10.8 ± 3.5	male: 11.4 ± 3.6	
	female: 25.9 ± 4.9	female: 24.4 ± 4.5	
Technician 2; Trial 2	18.5 ± 8.8	18.0 ± 7.7	
	male: 10.7 ± 3.5	male: 11.5 ± 3.9	
	female: 25.9 ± 5.1	female: 24.2 ± 4.6	