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EVALUATION OF BODY FAT PREDICTION EQUATIONS FROM A PORTABLE A-MODE ULTRASOUND (BODYMETRIX) COMPARED TO BOD POD

By

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A plan B research project submitted in partial fulfillment
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of

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in

Health and Human Movement

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Summary

A-mode ultrasound is a relatively inexpensive and noninvasive way of measuring subcutaneous fat thickness and estimating body fat percentage (%BF). The BodyMetrix BX2000 A-mode ultrasound is programmed with nine different equations that can be used to estimate %BF. The purpose of this study was to compare the %BF estimation from all nine equations available for adult males in this ultrasound system to the %BF estimation from Bod Pod air displacement plethysmography. Ultrasound measures were taken at 10 body sites on 42 males of varying age (28.6 ± 11.9 y), height (182.4 ± 7.6 cm), weight (84.5 ± 16.9 kg), and body mass index (24.5 ± 4.6 kg/m^2). The %BF from the nine ultrasound formulas were compared to the estimate from the Bod Pod with a repeated-measures ANOVA. Three of the nine equations -- the Jackson and Pollock 3 site (JP3), Jackson and Pollock 7 site (JP7), and the NHCA 4 site -- had acceptable correlation coefficients (> 0.80), low mean differences that were not significant ($p > 0.05$), and insignificant bias. None of the equations had errors < 3.5%BF, but all three of these formulas had standard error of estimate (SEE) and total error (TE) of about 4%BF. Based on these findings, the JP3, JP7, and NHCA 4-site formulas in the BX2000 A-mode ultrasound are recommended over the other formula options for estimating the %BF of men.

Keywords: air displacement plethysmography, body composition, prediction, subcutaneous fat, validity

Introduction

Many people strive to live an active and healthy lifestyle with the goal to improve their overall health. An important component to consider when determining one's overall health is percentage of body fat (%BF). One of the most common methods to estimate %BF is skinfold measurements. However, it requires considerable practice and skill to perfect the skinfold measurement technique. Further, a skinfold is an indirect measure of subcutaneous fat because the fat is compressed, and there is a double layer of skin (Heyward & Wagner, 2004). Alternatively, ultrasound provides a direct method of measuring subcutaneous fat thickness without tissue compression (Wagner, 2013). Additionally, the test-retest reliability and inter-rater reliability of the ultrasound method to estimate %BF is superior to the skinfold method (Wagner et al., 2016).

As the name implies, ultrasound operates at frequencies above what is audible by the human ear. The sound wave is partially reflected back to the transducer as an echo when it comes in contact with a tissue interface, such as the fat-muscle interface. The technical principles and procedures for using ultrasound to measure adiposity have previously been reviewed (Bazzocchi et al., 2016; Wagner, 2013). The reflected echo produces a two-dimensional image of the underlying tissues during brightness modulation (B-mode) ultrasound. People are most familiar with this mode of ultrasound; however, amplitude modulation (A-mode) ultrasound also exists. Rather than an image that is produced with B-mode ultrasound, A-mode ultrasound results in a graphical spike at the fat-muscle interface. A-mode ultrasound has recently been validated against B-mode ultrasound and cadaver dissection for measuring subcutaneous fat at individual sites, with each site measurement correlating at .90 or above (Wagner et al., 2019).

The BodyMetrix BX2000 (IntelaMetrix, Inc., Livermore, CA) is a 2.5 MHz A-mode ultrasound that comes equipped with software (BodyView Pro) designed specifically to estimate %BF from ultrasound measurements of subcutaneous fat thickness at various sites. The software converts the ultrasound-measured fat thicknesses into an estimate of total %BF using popular skinfold formulas that have been proprietarily modified for ultrasound measurement. The BodyView Pro software that accompanies the BodyMetrix BX2000 A-mode ultrasound includes nine different equations to estimate %BF in adult males. These equations with the corresponding measurement sites are described in Table 1. Despite nine options available in the software to estimate %BF, most researchers who have conducted validity studies of the BodyMetrix system on adult males have evaluated only the Jackson and Pollock 3-site (JP3) formula (Johnson et al., 2012; Loenneke et al., 2014; Wagner et al., 2016) or the Jackson and Pollock 7-site (JP7) formula (Johnson et al., 2014; Smith-Ryan et al., 2014). Baranauskas et al. (2017) included the 3-site Pollock formula with the two Jackson and Pollock formulas in their evaluation of the BX2000 against dual-energy X-ray absorptiometry. Nevertheless, most of the other prediction formulas programmed into the BodyMetrix system have yet to be evaluated. Thus, the purpose of this study was to compare the %BF estimation from all nine equations available for adult males in the BodyMetrix A-mode ultrasound system to the %BF estimation from the Bod Pod air displacement plethysmography system (Cosmed USA, Inc., Concord, CA).

Methods

Ethics Statement

This study was approved by the Institutional Review Board of Utah State University (protocol #9696). All participants were informed of the benefits and risks of the study prior to signing an informed consent document.

Design

This was a repeated-measures design such that all participants in the study had their body composition measured by an A-mode ultrasound machine and the Bod Pod in a single session. Two data collectors were present at each session. One data collector was responsible for recording the participant's height, weight, and setting up the participant's BodyMetrix profile with a patient identification number. The other collector marked the participant with a surgical marker at the sites to be measured and performed the ultrasound measurements. Both collectors then worked together to obtain the participant's Bod Pod measurement. The two data collectors performed the same procedures for each participant to ensure consistent data collection.

Participants

Forty-two males participated in this study. Participants learned of the study by posted advertising and word of mouth. Males aged 18 to 65 y of all body types, varying in height and weight, were encouraged to participate. Any persons with loss of limb were excluded from this study due to the inability to measure all of the ultrasound sites.

Preliminary Procedures

Each participant had data collected in one session lasting approximately 45 minutes. Participants were required to refrain from food, drink, and extreme physical activity for 2 hours prior to their data collection session. Upon arrival, the examiners reviewed the informed consent with the participant, detailing the procedures, benefits, and risks of the study before taking measurements. Participants voided their bladder and bowels if needed before any measurements. Height was measured to the nearest 0.1 cm using a wall mounted stadiometer (Seca 216, Seca corp. Ontario, CA). Weight was measured to the nearest 0.1 kg using a digital scale (Seca 869, Seca corp. Ontario, CA). Participants were wearing only lycra Spandex shorts for these and all subsequent measurements. Date of birth was obtained to determine age. Participants were then measured with the A-mode ultrasound machine (BodyMetrix BX2000, IntelaMetrix Inc., Livermore, CA) followed by the Bod Pod.

A-mode ultrasound

The ultrasound device was used in conjunction with the software provided by IntelaMetrix, Inc. (BodyView Professional Software). One examiner set up the subject's profile on the provided software. The examiner decided on a body type for each participant as outlined by the software. Body types included elite, athlete, and non-athlete. Elite is described as a very active person, with visible musculature, including "six-pack" abdominals. Athlete is described as a normal active person with some musculature and not obviously overweight. Non-athlete is described as someone who is not active, and who is visibly overweight or obese. The subject was then marked with a surgical marker at each of the 10 sites to be measured (Table 2). Doing so aided the accuracy of the measurement

(Heyward & Wagner, 2004). Site-point ultrasound measurements were taken according to the manufacturer's guidelines. Measurements were repeated according to the software prompts, and results were saved for subsequent analyses. The software automatically selects the peak that corresponds to the fat-muscle interface, but the technician could override the default and select a different peak if there was reason to do so. The proprietary software automatically calculated the estimated %BF for each ultrasound formula.

Bod Pod

Following the collection of the ultrasound measurements, participants underwent a Bod Pod measurement to determine %BF. The Bod Pod was calibrated according to the manufacturer's guidelines. Thoracic gas volume was measured rather than predicted to maximize the accuracy of the Bod Pod method. The Siri (1961) formula was used to convert body density into %BF.

Statistical Analyses

All data were analyzed using SPSS version 25 (IBM, Inc., Armonk, NY). Statistical significance was accepted at $p < 0.05$. Means and standard deviations were calculated for all variables, and data were assessed for normality. Estimates of %BF from the various ultrasound prediction formulas were evaluated against the estimate from the Bod Pod with a repeated-measures ANOVA. Following a significant F-score, post-hoc pairwise comparisons with Bonferroni adjustment were made. For an equation to be deemed valid there should be no significant difference between the ultrasound formula and the Bod Pod. Other evaluation criteria which has been determined in previous research for accepting validity included a Pearson correlation coefficient > 0.80, standard error of estimate (SEE) and total error (TE) < 3.5%BF, and no systematic bias in the Bland and Altman (1999) plot of residual scores. These criteria for evaluating the validity of body composition methods and prediction equations were initially established by Lohman (1992) and have been recommended in subsequent body composition assessment texts (Heyward & Wagner, 2004; Lohman & Milliken, 2020).

Results

The sample varied in age (28.6 ± 11.9 y; 18 to 57 y), height (182.4 ± 7.6 cm; 166.0 to 197.0 cm), weight (84.5 ± 16.9 kg; 59.1 kg to 132.3 kg), and body mass index (25.4 ± 4.6 kg/m^2; 19.7 to 39.9 kg/m^2). Despite the heterogeneity of the sample, it was skewed toward lean participants with 16 being classified as “elite” (very lean) body types, 18 “athletic” (normal), and 8 “non-athletic” (overweight or obese). Eighteen of the 42 participants were unable to perform the breathing maneuver successfully to obtain a valid measure of thoracic gas volume during the Bod Pod test; thus, their predicted thoracic gas volume was used. Research suggests that, on average, the difference between predicted and measured thoracic gas volumes is not significant (Collins & McCarthy, 2003; McCrory et al., 1998; Wagner, 2015). One participant was a statistical outlier for the Sloan 2-site equation. He was removed from the analysis for this equation but remained for all other analyses.

Data comparing the Bod Pod and ultrasound equations are presented in Table 3. Eight of the nine equations met the criteria of a Pearson correlation coefficient ≥ 0.80. However, the mean differences in %BF between the Bod Pod and four equations (1-point biceps, Forsyth & Sinning 4-site, Durnin & Womersley 4-site, and Parrillo 9-site) were statistically significant and very large. Of the remaining equations, both the Sloan 2-site and the Pollock 3-site had significant systematic bias, with the Sloan 2-site having high

SEE and TE as well. With the exception of a slight bias for the JP7 (r = 0.34, $p = 0.03$), the remaining three equations (JP3, JP7, and the NHCA 4-site) had acceptable correlation coefficients, low mean differences, and no bias. None of the equations had errors < 3.5%BF, but all three of these formulas had SEE and TE of about 4%BF. The linear regression and the Bland and Altman (1999) plot of residual scores for the %BF estimation from the JP3 equation compared to Bod Pod are depicted in Figures 1 and 2, respectively.

Discussion

The purpose of this study was to obtain and compare %BF estimations from all nine equations provided by the software that accompanies the BodyMetrix A-mode ultrasound system to the %BF estimation from the Bod Pod in a sample of adult males to determine which ultrasound equations, if any, accurately estimate %BF. Of the nine equations, none were "ideal," as they all exceeded the predetermined TE criterion of 3.5% BF. However, three equations had SEE and TE of about 4.0% BF; this is a "fairly good" estimate of %BF using the subjective rating scale as described by Heyward and Wagner (2004) and Lohman and Milliken (2020). The JP3 measurement had the lowest mean difference and bias of all the equations measured, but a slightly higher SEE than either the JP7 or NHCA 4-site equations. The JP7 had the lowest SEE and TE (both < 4.0% BF), but a slight significant bias. The NHCA 4-site measurement had the largest mean difference of these three equations, but no bias, and SEE and TE similar to the two Jackson and Pollock equations. Considering the aggregate of the predetermined validation criteria, these three equations best met the criteria of the nine equations evaluated.

Other studies have compared a few of the BodyMetrix prediction equations to estimate %BF against other body composition methods. However, this is the first study to analyze all nine equation options in the BodyView Pro software and determine their accuracy compared to %BF measured by a Bod Pod. Previous researchers have done BX2000 validation studies using the JP3 formula, the JP7 formula, and the 3-site Pollock formula. Johnson et al. (2012) reported a Pearson correlation coefficient of 0.88 (nearly identical to ours of 0.86) between the JP3 and Bod Pod with no significant difference in mean %BF between the BX2000, Bod Pod, and bioelectrical impedance. Wagner et al. (2016) reported an overestimation of about 3% BF for the BX2000 compared to the Bod Pod in a sample of 45 collegiate athletes of mixed gender, with an SEE of 2.6% BF and TE of 4.4% BF. However, when only the males were considered, the difference between the %BF estimate from the JP3 and Bod Pod became nonsignificant, and the TE dropped to 2.8% BF. Loenneke et al. (2013) compared both the 1-point biceps and JP3 ultrasound measurements to skinfolds. Although they reported no significant difference in %BF between either the 1-point biceps ($p = 0.999$) or JP3 ($p = 0.314$) and skinfolds, the SEEs between the two methods exceeded 7% BF for both equations. However, this was a very small sample of 8 men and 3 women. Both Johnson et al. (2014) and Smith-Ryan et al. (2014) used the BX2000 JP7 formula in their studies. Johnson et al. (2014) reported that JP7 underestimated %BF by about 4% ($p < 0.001$) compared to dual-energy x-ray absorptiometry, but when their sample was split by sex the two methods were not significantly different ($p = 0.54$). Smith-Ryan et al. (2014) found that the ultrasound JP7 underestimated %BF of overweight and obese adults by an average of 4.7% BF ($p < 0.001$) compared to a 3-component model of body density from the Bod Pod and water from bioimpedance spectroscopy. Their sample was a mix of males and females, but the results were not stratified by sex, making it difficult to compare to the present study of all males. Lastly, Baranauskas et al. (2017) used the BX2000 to estimate %BF using both the JP3 and JP7 formulas as well as the Pollock 3-site. All three formulas underestimated %BF compared to dual-energy-x-ray absorptiometry by 3.6% to 5.2% BF ($p < 0.001$). Again, this was a mixed sample making it difficult to compare to the present study of males.

A number of %BF prediction equations had poor validity in the present study. One reason for this may be that some of the original skinfold prediction equation were created for a specific body type or population, and thus the BodyMetrix proprietary conversion of these formulas may not be well suited for the general public or a heterogeneous sample as was used in the present study. For example, the 9-site Parrillo equation was first presented in a book for body builders, and sex was not an independent variable in this formula (Parrillo & Greenwood-Robinson, 1993). Another %BF equation, the Forsyth and Sinning 4-site, was created for male athletes of lean body weight (Forsyth & Sinning, 1973). Something else to consider is the number and location of body sites measured. For example, the 1-point biceps measurement may not be accurate because of the lack of measurements and body sites used to estimate %BF. In contrast, the most accurate equations at measuring %BF, the JP3 and JP7 equations, were created for the use of the general public (Jackson & Pollock, 1978); thus, providing a more accurate estimate of %BF for our heterogeneous sample.

There are some additional points and limitations to consider in the evaluation of the nine equations provided by the BodyMetrix BX2000 ultrasound device. First, our sample was skewed toward “elite” and “athletic” body types with fewer “non-athletic” participants.

Previous research suggests that the BX2000 underestimates %BF in an overweight or obese sample (Smith-Ryan et al., 2014). In general, the equations in the BX2000 overestimated the Bod Pod %BF in the present study. If Smith-Ryan et al.'s result is generalizable to other samples, having more obese men in the present study might have offset the significant mean overestimations of some of the prediction equations. Findings from the present study are also limited to males. There are an additional 10 BX2000 prediction equations for females that have yet to be evaluated. Finally, the Bod Pod served as the criterion method to estimate %BF and was assumed to be valid. Some research suggests that the Bod Pod underestimates %BF for very lean individuals (Peeters et al., 2013), and this could have contributed to the difference in %BF between methods. However, in a review of the air displacement plethysmography method, Fields et al. (2002) determined that the Bod Pod is within 1% BF of other reference methods such as hydrodensitometry and dual-energy x-ray absorptiometry.

In summary, even though nine %BF prediction equations are provided for males in the BX2000 ultrasound system, only three had acceptable accuracy compared to the Bod Pod in this sample of males aged 18-57 y. Based on these findings, when using the BodyMetrix BX2000 to estimate %BF of males, we recommend selecting either the JP3, JP7, or NHCA 4-site equation.

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Conflict of Interest

The authors have no conflict of interest.

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