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Three-Dimensional Body Scanning as a Novel Technique for Body Composition Assessment: A Preliminary Investigation

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ABSTRACT

Ryder, JR, Ball, SD. Three-Dimensional Body Scanning as a Novel Technique for Body Composition Assessment: A Preliminary Investigation. **JEPonline** 2012;15(1):1-14. Three Dimensional (3D) body scanners are novel technologies for the assessment of body volume. The purpose of this study was to determine if 3D body scanning can be used as an accurate method of body composition assessment. Eighty-five male subjects (21.7 ± 2.3 yrs old; 81.0 ± 12.2 kg; 25.4 ± 3.4 kg/m^2) completed Duel X-Ray Absortometry (DXA), Bod Pod, and 3D body scanning. Comparisons of body fat percentage (BF) indicated significant differences between 3D body scanning, DXA (BF = 16.3 ± 4.7%), and Bod Pod (BF = 12.2 ± 7.2%). A prediction equation (3D MU) was created and showed improvement over currently used scanner equations by the Department of Defense (DoD), (3D MU = 16.5 ± 4.2%, SEE = 3.09%; DoD = 13.5 ± 6.4%, SEE = 3.67%) when compared to DXA. Although the 3D body scanner shows promise as a method of evaluating BF, more refinement is needed before it can be used as a method of assessment.

Key Words: Body Composition, 3D Body Scanning, Duel X-Ray Absortometry

INTRODUCTION

Body composition is the specific amount of adipose tissue, muscle tissue, and bone present in the body. Although not technically correct, most often the term is used to represent only the amount adipose tissue or percentage of body fat (BF) present. High amounts of adipose tissue or BF have been shown to be detrimental to one's health and increased disease risk (2,33-34,41-42,48). Obesity, which can be defined as having excess BF is a leading cause of hypertension, hyperlipidimia, and type II diabetes (4,11,34,43,51). According to the Center for Disease Control (20), these conditions are two to three times more prevalent in obese individuals than normal weight individuals. Accurately measuring BF is a valuable resource for fitness and health professionals. It is needed to assess health risk, to monitor changes in BF with certain diseases, to formulate dietary recommendations and exercise prescription, to estimate ideal body weight of clients and athletes, and to monitor growth, development, maturation, and age related changes in body composition (23).

The basic theoretical model of body composition is the two compartment model (2C). The 2C model divides the body into two categories: fat mass (FM) and fat-free mass (FFM). The FM consists of all extractable lipids from adipose and other tissues, while FFM includes all residual chemicals and tissues (i.e., water, muscle, bone, connective tissue, and internal organs) (32). This theoretical two compartment model is the most basic model of body composition. It is the foundation for estimating BF. The 2C model is the basis for assessment techniques such as hydrostatic weighing (HW) (15), air displacement plysmography (Bod Pod), (6,12) and skinfolds (SKF) (16,32). Multicompartment models (3C, 4C, and 5C) add additional accuracy by measuring one or more constituents of the FFM. For example, Dual Energy X-Ray Absorptiometry (DXA) measures bone density making it a 3C model of body composition. However, the cost and difficulty of using multicompartmental models, especially 4C and 5C, limit their use in most settings.

Choosing the most accurate method to assess BF depends on accessibility to equipment. Although DXA, HW, and Bod Pod are considered to be the most accurate assessments, most practitioners do not have access to these techniques (14,40,46,50,52). Therefore, field methods such as Body Mass Index (BMI), SKF, anthropometric measurements, and bioelectrical impedance (BIA) are used (5-7,24,38). Practitioners use these methods due to their availability and cost. Given that accuracy is important, body composition researchers and practitioners are constantly searching for better, non-problematic, and cost effective methods to determine BF. The assessment techniques discussed above will continue to be used until a new method emerges that is accurate, quick, easy to perform, and cost effective. One possible technique might be three-dimensional (3D) body scanning.

Three-Dimensional Body Scanning.
The 3D body scanner was originally developed to be used in the apparel industry. Body scanners use light to illuminate an object, or in this case the human body, while a series of cameras capture reflected light resulting in a detailed digital 3D image. This form of the technology is known as fan-beam technology. Other 3D scanning devices exist which use laser technology, but are not applied in this method of assessment (22). Using fan-beam technology allows for linear, two- dimensional and three-dimensional measurements of the body's surface. The body measurements are very precise, and the measurements are more accurate than typical anthropometric measurements determined by tape measures, sliding calipers, and other devices (21-22). Also important, since the scanner can measure total body volume, BF should be able to be predicted by calculating body density. The scanner is thus a 2C model, in theory, that might have promise as an important method to assess BF. The scanning procedure is very fast (5 secs) and completely non-invasive, which allows for mass testing. To our knowledge, there are no studies to date that have compared 3D scanners, using fan beam technology, to estimate percent BF to DXA or any other laboratory method. The purpose of

this preliminary investigation is to determine if 3D body scanning can be used as an accurate method to assess body composition.

METHODS

Subjects

Ninety-seven male subjects were recruited for this study. Eighty-five subjects were used for final analysis. The subjects were 18 to 30 yrs of age. They were informed of the research procedures, the risks involved, and signed an informed consent form in accordance with the policies and procedures of the University of Missouri Human Subjects Institutional Review Board.

Subject Preparation

The subjects were instructed not to eat or consume water 2 hrs prior to testing. They were asked to refrain from exercise 4 hrs prior to testing. Also, they were asked to remove all jewelry and wore required to wear non-metallic or plastic clothing. While in the Bod Pod, the subjects wore a swim cap and were measured in their underwear or small shorts. For all anthropometric measurements, the subjects wore shorts only. In the 3D body scanner, the subjects wore grey boxer briefs. For the remainder of the tests, the subjects wore shorts and a T-shirt. All tests were completed on the same day within 2 hrs of each other. Testing order for each subject was as follows: height, body weight, DXA, Bod Pod, anthropometric measurements, hand volume, foot volume, and 3D body scanning.

Anthropometric Measurements

Anthropometric measurements were taken following American College of Sports Medicine guidelines (1). The subjects' body weight was measured to the nearest 0.5 lb using (Toledo scale, Mettler-Toledo Inc., Columbus, OH, USA), and height was measured to the nearest 0.25 inch using (Seca 216, Seca gmbh & co. kg., Hamburg, Germany). Circumference of the waist (narrowest point between the umbilicus and rib cage) and hip (largest protrusion of the buttock) were taken to the nearest 0.5 cm using a Medco Tape Measure (Medco Sports Medicine, Tonawanda, NY, USA). Body mass index (BMI; kg/m^2) and waist-to-hip ratio (WHR) were calculated as descriptive data.

DXA

Body composition was assessed with DXA (QDR 4500A, Hologic, Inc., Bedford, MA, USA) using fan beam technology. All subjects wore minimal clothing and removed all metal objects before being scanned and, then, they laid supine on the DXA table and were manually positioned by the researcher to manufacture specifications. Subjects were scanned once. Body composition was estimated using computer software (QDR Software for windows XP, Version 12.4, Hologic, Inc., Bedford, MA). Bone mass, fat mass, and lean tissue mass were represented in grams. The subjects' BF was calculated by software that represented fat mass (g)/ total mass (g) x 100.

Three-Dimensional Body Scanner

Body scans were collected on all subjects using Textile/Clothing Technology Corp. ($[TC]^2$), 3D body scanner (Cary, NC, USA). Subjects removed all jewelry and wore only gray knit cotton undershorts while in the scanner. A 3D body image was created using $[TC]^2$ body imaging software. They were required to remain in the 3D body scanner until a good body image was output by the software. From the body image a bulk body volume was obtained. Bulk volume removes hands, head, and feet from the total volume. In addition to comparing BF from the scanner to BF via DXA, the $[TC]^2$ fitness equation (22), created by the DoD, was compared to BF by DXA. All scans were conducted by the same trained technician.

Bod Pod

Body Composition was assessed using the Bod Pod (Life Measurements, Inc., Concord, CA, USA) in order to compare the BF from Bod Pod to that of the 3D body scanner. The Bod Pod is a dual chambered air-displacement plethysmograph that employs the densitometric approach to assess body composition. Subject mass was measured using an electronic scale, attached to the Bod Pod, which was calibrated to within ± 0.05% of 20 kg calibration weights. Subject body volume was measured in an enclosed chamber using the relationship between pressure and volume. Chamber air volume was determined both with and without a subject in the test chamber, with the difference between the two measures yielding the subject's body volume. Body volume was measured at least twice and three times if the first two measurements were not within 150 ml or 0.3%. If no two measures met the acceptance criteria for a subject, the entire test procedure was repeated. Body volume was corrected for thoracic gas volume in the lungs via a prediction equation (36). The BF measurement was derived by using the two-compartment Siri equation (35-36,47). All calculations were performed by the Bod Pod's software (version 1.91).

Statistical Analysis

The SPSS version 17.0 was used for statistical analysis. Pearson correlation and coefficient of determination, R^2, were assessed to determine the reliability of the measures. Standard estimation of error (SEE) was used to assess the quality of the regression equation created. DXA was used as the criterion measure of body composition assessment to which scanner and Bod Pod BF were compared.

Reliability

A highly trained technician performed all measurements. Intra-tester reliability (anthropometric measurements), reliability of DXA, reliability of Bod Pod, and reliability of 3D body scanner were conducted on 10 subjects by repeating the measurements after a brief break that included repositioning the subject. A correlation between the trials was performed to determine reliability.

RESULTS

Ninety-seven male subjects were recruited for the study and 85 subjects were used for final analysis. Table 1 shows subject characteristics with outliers removed. Outliers were determined to be ± 3 standard deviations from the mean using 3D body scanner BF (3D SCAN) as the method of evaluation. Percent BF via DXA, Bod Pod, 3D SCAN, and the scanner's current prediction equation developed by the Department of Defense (DoD) are compared in Table 2. The 3D SCAN and the Bod Pod BF were computed using the Siri equation (10,48). A new prediction equation (Table 3) using 3D body scanning was also computed using a DXA correction factor equation labeled 3D MU.

Table 1. Descriptive data of the subjects.

	Mean ± SD	Range
N	85	
Age (y)	21.7±2.3	13-30
Height (m)	1.7±0.7	1.41-1.96
BMI (kg/m^2)	25.37±3.40	19.38-40.77
Waist Circumference (cm)	82.2±8.7	63.1-122.3
Hip Circumference (cm)	97.9±6.6	84.3-120.8
WHR, Waist-to-hip ratio	0.84±0.06	0.60-1.01

Table 2. Body composition comparisons.

	Mean ± SD	Range	Mean difference from DXA	Pearson correlation (*r*) with DXA	Adjusted R^2 with DXA	Standard Error of Estimate (SEE) with DXA
DXA BF	16.30±4.67	8.20-32.80.				
Bod Pod BF	12.17±7.19	1.23-37.68	-4.13	0.856**	0.729	2.45
3D SCAN BF‡	9.60±12.22	-15.11-53.89	-6.70	0.237*	0.045	4.59
DoD BF†	13.53±6.43	5.35-54.45	-2.77	0.629**	0.388	3.67
3D MU BF #	16.49-4.16	11.03-31.73	0.19	0.759**	0.571	3.09

* p <0.05
**p<0.01
‡ 3D Body Scanner BF using Siri equation
†Based upon the Department of Defense circumference equations used by [TC^2] software (23)
#3D Body Scanner BF using created correction equation

Table 3. Correction equation with randomly assigned group of n = 60, cross validated by n = 25.

Random group (*n*=60)		
	DXA BF	16.41±4.93
	3D MU correction equation	-20.361 + 1.018(abSCAN*) + 0.052(3D SCAN‡)
	3D MU BF (*n*=60)	16.54±4.26, r^2 adj.= 0.695 SEE= 2.77%
	Cross-Validation (*n*=25)	16.39±4.00, r^2 adj.= 0.679 SEE=3.32%

* abSCAN = Abdominal measurement from 3D Body Scanner
‡ 3D SCAN = Siri equation estimated BF from 3d Body Scanner

Inter-method Body Composition Comparisons

Body composition correlations, adjusted R^2, and standard error of estimate using DXA as the criterion are shown in Table 2. Figure 1 represents a Bland-Altman plot illustrating the underestimation of the 3D SCAN compared to DXA. Figure 2 is a Bland-Altman plot comparing DXA and the 3D MU BF.

Development of the 3D MU Correction Equation

Table 3 shows the 3D MU correction equation created from a random sample of 60 subjects and then cross validated on the remaining 25 subjects. Predictors in the correction equation were determined via stepwise regression based upon the correlation to DXA. Abdominal circumference determined by the scanner combined with 3D SCAN explained the most variance with the least amount of error.

Reliability of measures

Table 4 shows the reliability testing of DXA, Bod Pod, and 3D SCAN on 10 subjects repeated twice.

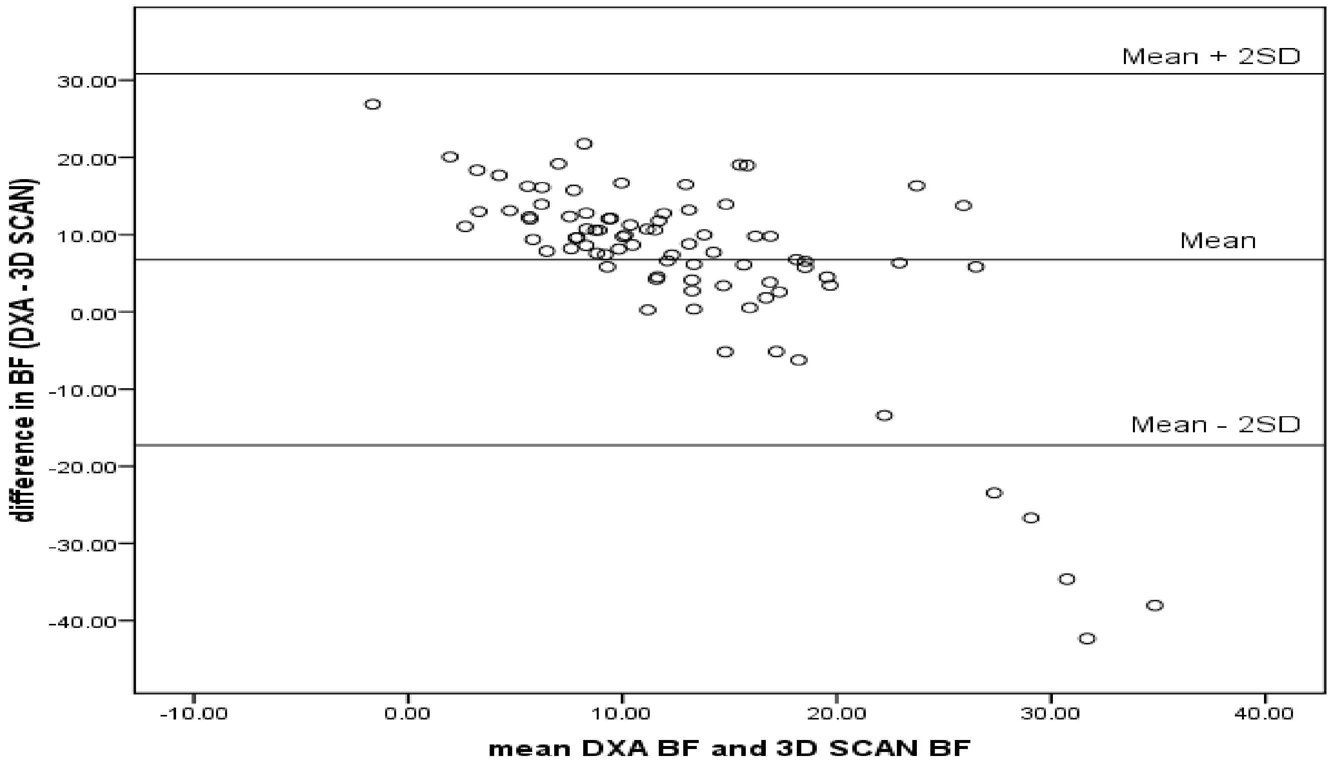

Figure 1. Bland-Altman plot (Differences against mean of BF) for DXA versus 3D SCAN.

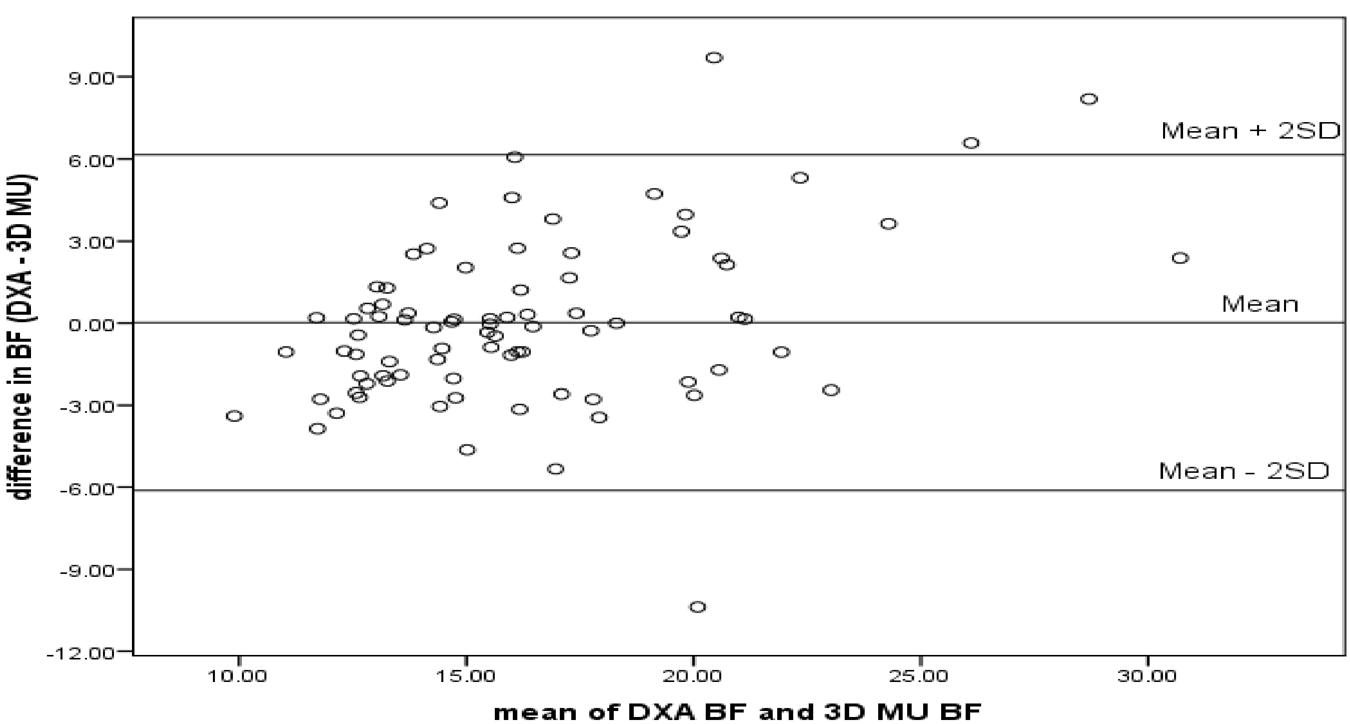

Figure 2. Bland-Altman plot (Differences against mean of BF) for DXA versus 3D MU.

Table 4. DXA, Bod Pod, and 3D Body Scanner reliability.

	Correlations		Paired t-test			
Method	***r***	**P**	**Mean difference**	**SEM**	**T**	**P**
DXA	0.997	<0.001	0.1000	0.0538	1.861	0.960
Bod Pod	0.993	<0.001	0.1400	0.2342	0.598	0.565
3D Body Scanner	0.922	<0.001	0.0899	0.1101	0.817	0.435

Reliability of body composition methods, *n*=10 repeated twice on same day
Accept null hypothesis for all (means are equal)

DISCUSSION

The 3D body scanner shows promise as a fast, accurate, comfortable, and non-invasive method of measuring body composition. However, until now no study has investigated its accuracy compared to DXA. It was hypothesized that 3D body scanning would be as accurate as other 2C models at predicting BF compared to DXA. In its current form, the 3D body scanner underestimates BF compared to DXA. However, the underestimation is consistent across BMI levels signaling the need for a new prediction equation to be created to account for the difference. When the 3D MU correction equation was employed the 3D scanner appeared to be as accurate as other 2C models (Bod Pod) at predicting BF. The 3D MU equation had a mean difference of 0.2% BF compared to DXA with a low SEE of 2.77% (Table 3). According to Lohman's (30) subjective rating scale, the 3D scanner would score as a "very good" to "excellent" method of estimating BF. Further, the 3D MU equation would meet Lohman's (30) standard acceptability criteria outlined for cross validating equations.

Previous studies by the United States Department of Defense (DoD) have looked at using 3D body scanning, using digital laser scanning, as a novel and effective method of assessing body composition (21). However, instead of using body volume to calculate density and fatness, Garlie and colleagues (21) used circumferences to predict BF. Comparing BF of 37 white males attained from DXA and 3D body scanning, linear regression analysis from circumferences revealed a moderate, statistically significance relationship ($P<0.05$) and Pearson correlation coefficients with moderate standard errors ($R^2 = 0.74$, SEE = 3.3%). Generally, using circumferences as a measure of BF is considered to be a crude measure with much variability (24,31). Later, follow up to this investigation by the same group was published (22) using the same digital laser technology and showed similar results.

Comparison of 2C models (Bod Pod and 3D Scanner) to DXA

DXA was chosen as the criterion method in part because it has shown to be a very reproducible method (~1% BF) (26). In this study, DXA was found to be reliable with a mean difference of 0.1% BF between trials ($n = 10$; $r = 0.997$; $P <0.001$). Many researchers favor DXA over multicomponent models because it is fast, easy, and can be used on wide variety of populations (3,7-8,28). DXA is currently called the "practical gold standard" of body composition assessment techniques and is widely used to compare other techniques against (5).

In the current study, both the Bod Pod and the 3D MU were significantly and similarly correlated to DXA ($P=0.001$). Previous studies comparing Bod Pod to DXA showed that the Bod Pod is an acceptable laboratory method of body composition assessment (19). Mean differences in the BF measured by the Bod Pod and DXA have varied but are similar (-3.9 to 1.7 % BF) (12, 29, 37, 44, 49). The current study shows a mean difference between Bod Pod and DXA to be -4.13% which is similar and consistent to previous findings by Fields and Goran (17). The fact that the current data comparing Bod Pod and DXA are similar to other findings helps to determine where the differences in 3D scanner BF might exist and, therefore, allows for a comparison between a current acceptable 2C model (Bod Pod) and a possible new method of assessment (3D body scanner).

The 3D body scanner corrected by 3D MU correction equation had a mean difference of 0.2% BF and was significantly correlated to DXA ($P = 0.01$). The 3D MU had a more similar mean and SD with less SE than the Bod Pod compared to DXA. The 3D scanner has several advantages over the Bod Pod: (a) speed (~3 times faster); (b) less subject cooperation is necessary; and (c) minimal technician training is required. Additionally, the 3D scanner does not suffer from environmental changes. The Bod Pod is sensitive to changes in temperature, humidity, and pressure making in a finicky device (6,18,35). Nevertheless, the Bod Pod has been through much scientific rigor making it a popular and accepted laboratory measure of body composition assessment for many different populations. Despite the current positive results, scanning technology for measuring fatness is in its infancy. Many more investigations must take place before the 3D scanner might be regarded as accurate, reliable, and reproducible as the Bod Pod.

DoD versus 3D MU

The 3D MU correction equation shows a significant improvement over that of the original [TC^2] BF estimation equation created by the DoD (22). The DoD equation significantly underestimated BF compared to DXA (2.8%). The DoD equation also had a much wider range (5.4 to 54.5%) compared to DXA (8.2 to 32.8%). BF by the DoD is determined by circumference measurements, which not surprisingly, typically do not accurately predict body fatness (45). Obviously, circumferences are not the most accurate means of determining BF, because it is impossible to determine how much muscle or fat is underneath the skin. Typically, when BF is predicted by circumferences, it has a very high error. Studies comparing this method to HW showed a 6.8 to 18% false positive rate for individuals declared as having excess body fat (45). In addition, research suggests circumferences are even less accurate for individuals with very low or very high BF (9). Our population consisted of leaner individuals (16.3% BF) and thus might further explain why the DoD equation did not accurately predict BF in this sample. It appears that the 3D MU equation is a better alternative to the currently employed equation. When compared to DXA over the entire sample, the mean difference of the DoD was 2.77% with a SEE 3.67% compared to that of 0.2% with a SEE 3.09% using 3D MU equation.

Limitation and Sources of Error

While there were 97 subjects that completed the study, only 85 subjects were used for final statistical analysis or ~88% of the total subjects. The subjects removed from the data set met two criteria: First, they were ±3 SD from the mean of the 3D body scanner BF and, second, they exhibited “influence” if not removed. Influence was determined by using Cook’s *D* which is frequently used to calculate the leverage that specific cases may exert on the predicted value of the regression line (39). There were 12 outliers using 3D SCAN as the criterion. However, if the criterion was switched to DXA there were zero outliers, and if switched to Bod Pod there were two outliers (both of which were also outliers with 3D SCAN). The variability with the 3D body scanner is higher than with other methods and needs to be improved upon in order for 3D body scanning to be a valid method of assessment in the future. Examining standard protocol for 3D body scanning to make it consistent for each subject could help with limiting false positive readings. Limiting the number of anomalous readings is of critical importance and an area that must be addressed by the manufacturer in order for this tool to be considered laboratory quality. It should be noted that other technologies, the Bod Pod in particular, were not perfect the first time they were applied to body composition assessment (13,18). In fact, the Bod Pod method underwent many technology and software advances in order to become a valid tool for body composition assessment.

One possible explanation for some of the non-normal results (outliers) is in the determination of body volume. Minor variations in volume will significantly alter density estimation and thus BF. Therefore, it is critical that body volume is measured as accurately as possible with as little error as possible. While 3D body scanning body volume was highly correlated to Bod Pod body volume ($r = 0.98$; $P = 0.01$), with similar means (data not shown), there was a slight underestimation of volume. The underestimation of volume would explain the underestimate of BF by the 3D scanner compared to DXA. Unfortunately, the 3D body scanner failed to give full volumes for the head, hands, and feet. Given that scanning technology's main use is to custom fit clothing, there is no reason for the device to precisely measure these body parts. In fact, only part of the head, hands, and feet are shown in the scanner output.

Although the scanner attempts to determine a volume for these segments, it appears to be a major limitation in determining total body volume. Volumes of the head, hands, and feet were measured manually, and an attempt was made to add the combination of these volumes to total body volume via the scanner. However, the addition of these volumes increased total body volume to a very high value, because the scanner is already partially measuring these body parts. Accurate determination of head, hands, and feet volume is an area that, if improved, might vault the 3D Scanner to the forefront of laboratory body composition assessment techniques. Without an improvement in this area, it is unlikely that the 3D scanner will replace currently employed methods.

One final source of error in determining body volume is the amount of hair on the head. The body scanner can only measure non-hair covered portions of the head. Individuals with significant amounts of hair will likely have additional underestimation of body volume and thus body fat. Perhaps, by wearing a swim cap this can be improved. However, we failed to account for this and recognize it as a limitation. Future researchers should consider this fact, especially if they work with populations that have considerable head hair.

Although questions about scanner body volume exist, the scanner appears to very reliable. The 3D body scanner reliability testing ($n = 10$; $r = 0.922$; $P < 0.001$) was consistent and similar to DXA and Bod Pod reliability data (6). Reliability is a key factor for a technique to reach laboratory status. The fact that the 3D scanner is consistent is important and noteworthy. The $[TC]^2$'s 3D Body Measurement System uses a white light-based scanner and proprietary measurement extraction software. The scanner captures hundreds of thousands of data points of an individual's image and the software automatically extracts dozens of measurements (27). These measurements include circumferences and lengths of certain specified regions that can be combined in order to asses a bulk body volume of the subject. This volume can then be used for the purpose of body composition assessment. The scanner technology appears to be as reliable as other laboratory body composition assessment techniques.

The underestimation of BF via the scanner compared to DXA illustrates the need for a DXA based correction equation. A closer look at Figure 1 shows the underestimation to be fairly consistent across the population. If the underestimation was not consistent, then, the creation of a new prediction equation or correction factor would have been futile. The 3D MU equation was created in order to correct for this underestimation and when applied, (Figure 2) the difference between DXA and 3D MU is almost non-existent (0.2%). A valid prediction equation will not only have similar means, it will have a high R^2 and a low SEE (< 3.5%) when compared to the criterion (25). Particularly, the equation must have a low SEE, in which SEE is a measure of prediction error. The SEE is interpreted in the same way as the standard deviation. Thus, the larger the spread of scores is, the larger the deviation or error. A low SEE will yield a more accurate prediction equation with less variability. Determining the validity of these measures and assessing the accuracy of a new predication equation versus a criterion is essential for evaluating new methods of assessment. Lohman has outlined the ability to accept new equations on the basis of SEE and criterion for new prediction equations (30). The 3D MU has a SEE of 2.7% and thus meets Lohman's criteria for a prediction equation.

CONCLUSION

This study is the first to investigate the use of 3D body scanning technology for body composition assessment. Although the 3D body scanner shows promise as a method of evaluating BF, more work is needed before it can be considered an acceptable laboratory method of assessment. A 3D MU prediction equation was created that appears to be more accurate for young men than the current DoD equation. But, the 3D MU equation needs additional investigation and validation. Scanning technology must more accurately measure head, hands, and feet before it will be as accurate as other laboratory methods. Future research should focus on different populations and in determining possibly sources of error.

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