The Evaluation of a Circumference-based Prediction Equation to Assess Body Composition Changes in Men

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ABSTRACT

International Journal of Exercise Science 6(3) : 188-198, 2013. This study evaluated the validity of the current U.S. Department of Defense (DOD) circumference-based prediction equation for males to detect body composition changes in comparison to air-displacement plethysmography (ADP). Body composition was assessed using ADP and the DOD equation at the beginning and end of an academic school year among 21 male (18-29 years-old) Army ROTC cadets. Body mass significantly increased (+1.8 Kg) after 9 months. Significant method by time interactions for percent body fat (percent body fat), fat mass (FM), and fat-free mass were found (p = 0.022, p = 0.023, p = 0.023, respectively) as body composition changes were not tracked equally by the two methods. Regression and Bland-Altman analyses indicated a lack of agreement between methods as the DOD equation underestimated percent body fat and FM changes in comparison to ADP. Results suggest the DOD equation for males cannot adequately detect body composition changes following a small body mass gain.

KEY WORDS: Percent body fat, fat mass, fat-free mass, air-displacement plethysmography

INTRODUCTION

The physical fitness and health of U.S. military personnel is viewed as a key component of their operational effectiveness, combat readiness, and day-to-day functioning ability (35-37). To assist in maintaining physical fitness and health, U.S. military personnel are required to meet certain body composition standards. Military personnel who fail to meet these body composition standards may be penalized by being denied promotion or command positions (35-37).

Evaluation of body composition among U.S. military personnel is conducted at least once annually with screenings against established weight for height tables(34-37). Personnel exceeding threshold values of body weight based upon their height are typically further evaluated using a circumference-based method that predicts percent body fat (34-37). Circumference-based body composition assessments rely upon multiple site girth measurements (e.g., abdomen, neck, and hips) which are subsequently entered into regression derived prediction equations. Current circumference-based body composition assessments employed by the U.S. Army, Navy, and Marine Corps utilize the prediction equations and methodology outlined in U.S. Department of Defense (DOD) Instruction 1308.3 (34-37).

Over the last three decades, a number of circumference-based body composition prediction equations have been developed and employed in different branches of the U.S. Armed Forces (14, 15, 38, 41). Several studies have investigated the validity of these equations in assessing body composition against criterion measures such as hydrodensitometry (17), dual-energy X-ray absorptiometry (DEXA; 11), and 3-compartment models (26). In general, circumference-based assessments appear to provide reasonable body composition estimates at the group level; however, the individual level variability of these assessments can be rather high. This has led some to question the use of these equations when outcomes such as promotion might be adversely affected as a result of test inaccuracy (17).

One previous investigation by Friedl and colleagues (12) evaluated the ability of several circumference-based prediction equations to detect changes in body composition among females in comparison to DEXA. Results indicated that the equations for females did not accurately detect changes in body composition. However, the validity of circumference-based prediction equations to detect body composition changes among males in comparison to laboratory-based methods (e.g., DEXA, hydrostatic weighing, air-displacement plethysmography [ADP]) has not been investigated.

Therefore, the purpose of this investigation was to evaluate the validity of the DOD circumference-based prediction equation for males to detect body composition changes in comparison to ADP. To accomplish this aim, anthropometric and body composition changes were quantified from the beginning to end of an academic school year among an ethnically homogenous sample of male Army Reserve Officer Training Corps (ROTC) cadets.

METHODS

Participants

Body composition was assessed among a sample of 21 Caucasian male Army ROTC cadets (21.29 ± 2.39 yr) with ADP and a circumference-based prediction equation at the beginning (August 2010 [Pre]) and end (April 2011 [Post]) of an academic school year. Participants were active members of the Army ROTC which requires participation in mandatory academic coursework, physical training, and other extra-curricular activities. Cadets were recruited to participate in the study during one of their morning physical training sessions. Institutional Review Board approval was obtained prior to the start of the study. All participants signed informed consent forms after they were verbally informed of their rights as research participants and the risks associated with the study.

Protocol

At each assessment, participants arrived at the laboratory on a Tuesday between 6:00 and 8:00 a.m. Circumference measures were conducted first and followed immediately by ADP. Participants wore only form-fitted spandex bottoms during all assessments.

Circumference-based Body Composition Assessment: Measurements of height, abdominal circumference, and neck circumference were utilized to predict percent body fat. All measurements were taken with participants shirtless and in stocking feet. Height was measured to the nearest 0.5 inches using a portable stadiometer (SECA Road Rod #214; Seca GmbH & Co. KG, Hamburg, Germany). Circumferences were assessed using a non-stretchable fiberglass measuring tape according to the protocol outlined in DOD Instruction 1308.3 (34). Abdominal circumference was measured on bare skin at the level of the umbilicus and neck circumference was measured directly below the larynx. All measurements were taken by a trained technician who previously demonstrated an intraclass correlation coefficient (ICC) of 0.99 and a technical error of measurement (TEM) of 0.37 cm for repeated circumference measurements.

The percent body fat equation currently implemented in body composition assessments for the U.S. Army (35), Navy (36), and Marine Corps (37), and detailed in DOD instruction 1308.3 (34), was used to predict percent body fat from the previously described circumference measurements (all measurements in inches):

$$\text{Percent body fat} = (86.010 \times \log_{10}[\text{abdomen} - \text{neck}]) - (70.041 \times \log_{10}[\text{height}]) + 36.76$$

Fat mass (FM) was calculated as percent body fat obtained from the DOD equation multiplied by body mass. Fat-free mass (FFM) was calculated as body mass minus FM.

ADP: Total body volume (Vb) measured via ADP (BOD POD®; Life Measurement, Inc., Concord, CA) was utilized to estimate percent body fat. Previous research has demonstrated acceptable validity for ADP in assessing body composition against DEXA (4, 20, 28), hydrostatic weighing (5, 13, 21), and other 3- or 4-compartment models (1, 25, 26) including specifically in college aged individuals (4, 20, 25, 26) and adults (1, 5, 13, 21, 28). First, the BOD POD® was calibrated at the beginning of each testing session. Participants then had their body mass assessed using an electronic scale interfaced with the BOD POD® system. Before entering the capsule, each participant was fitted with a swim cap. Participants entered the capsule individually and completed two 50 s trials during which the BOD POD® measured raw Vb (Vb_{raw}). Participants were instructed to remain still and breathe normally while seated in the capsule. The BOD POD® system then averaged the two Vb_{raw} measurements if the difference in body volume was less than or equal to 150 mL. A difference greater than 150 mL required a third trial to be performed. If there was a difference less than or equal to 150 mL between two of the three measurements, those two measurements were then averaged. If none of the three measurements were within 150mL of any of the other measurements, then the entire test protocol was repeated. Measured Vb_{raw} was corrected using a predicted thoracic gas volume (TGV) provided by the BOD POD® system (8). Body density was derived by dividing body mass by the corrected Vb. Body fat percentage was calculated from body density via the Siri formula (33). FM was calculated as percent body fat measured via ADP multiplied by body mass. FFM was calculated as body mass subtracted by FM.

Test-retest reliability of the BOD POD® was assessed using a subsample of eight participants who completed an additional BOD POD® test. The second BOD POD® assessment repeated the entire BOD POD® protocol outlined above and was completed within 10 minutes of the first assessment. Paired *t*-test results indicated that mean (± *SD*) values of ADP estimated percent body fat among the subsample of eight participants from test 1 (17.7 ± 6.4) and test 2 (17.5 ± 5.6) were not significantly different ($t[7] = 0.576$, $p = 0.583$). The ICC and TEM for percent body fat between the two trials were 0.98 and 0.87%, respectively.

Statistical Analysis

All statistical analyses were completed using R version 2.13.0 (R Development Core Team; R Foundation for Statistical Computing, Vienna, Austria). Paired *t*-tests were used to compare pre and post measures of participant weight, body mass index (BMI), and anthropometric circumferences. Repeated measures analysis of variance (ANOVA) was used to assess changes in body composition variables (percent body fat, FM, and FFM) across time (pre vs. post) for the two methods (ADP vs. DOD equation). While investigating significant interactions, Bonferroni-corrected pairwise comparisons were used to control the family-wise error rate.

Linear regression analyses were conducted to assess the relationship between changes in percent body fat, FM, and FFM estimated by the DOD equation while using ADP as the criterion measure. The resulting fitted regression equations were analyzed to determine if the intercepts and slopes significantly differed from the line of identity (y = x; slope = 1, intercept = 0), with a non-significant finding indicating accurate prediction of changes in body composition variables by the DOD equation. Bland-Altman plots (6) were created to assess agreement between

Table 1. Physical and Body Composition Characteristics of Study Participants (n = 21)

Variable	*Pre*	*Post*	*Change*
Height (cm)	178.9 ± 5.7	179.4 ± 5.8	0.4 ± 0.7
Body mass (Kg)	78.8 ± 8.2	80.6 ± 7.8	1.8 ± 1.6**
BMI ($Kg{\bullet}m^{-2}$)	24.6 ± 2.3	25.2 ± 2.2	0.6 ± 0.5**
Abdomen circumference (cm)	83.1 ± 6.5	83.7 ± 6.5	0.6 ± 3.7
Neck circumference (cm)	37.0 ± 2.2	37.1 ± 2.0	0.2 ± 1.3
ADP			
Percent body fat (%)	13.1 ± 5.7	15.2 ± 6.0	2.1 ± 2.5**
FM (Kg)	10.5 ± 4.8	12.3 ± 5.2	1.9 ± 2.1**
FFM (Kg)	68.3 ± 7.0	68.2 ± 7.3	-0.1 ± 1.8
DOD equation			
Percent body fat (%)	15.3 ± 5.4	15.6 ± 5.3	0.3 ± 2.7
FM (Kg)	12.2 ± 4.5	12.6 ± 4.4	0.4 ± 2.3
FFM (Kg)	66.6 ± 6.7	67.9 ± 7.2	1.4 ± 1.9*

Note. Data reported as mean ± *SD*. BMI = body mass index; ADP = air-displacement plethysmography; DOD = Department of Defense; FM = fat mass; FFM = fat-free mass.*p < .05, **p < .01.

Table 2. Repeated measures ANOVA results for percent body fat.

Effect	*Sum of Squares*	*df*	*Mean Square*	*F*	*p*
Method	37.20	1	37.20	1.24	0.279
Error (Method)	602.02	20	30.10		
Time	29.41	1	29.41	7.56	0.012
Error (Time)	77.80	20	3.89		
Method*Time	17.10	1	17.10	6.12	0.022
Error (Method*Time)	55.89	20	2.80		

percent body fat, FM, and FFM change estimates from the DOD equation in comparison to ADP. The level of significance α was set at 0.05 for all analyses.

RESULTS

Pre and post results for anthropometric and body composition variables are presented in Table 1. Cadets within this sample gained approximately 1.8 Kg of additional body mass over 9 months ($t[20] = 5.24$, $p < 0.001$). This gain in body mass resulted in a significant pre to post increase in BMI ($t[20] = 5.23$, $p < 0.001$). Small and non-significant increases in abdominal and neck circumference were also noted.

Repeated measures ANOVA results for percent body fat are presented in Table 2. The main effect for method was non-significant while the main effect for time was significant. However, the main effects need to be interpreted with caution as a significant method by time interaction was found (Figure 1). No significant differences in percent body fat between methods were found when comparing pre and post results. Follow-up pairwise comparisons indicated percent body fat measured by ADP significantly increased from pre to post ($p = 0.004$), while percent body fat estimated by the DOD equation did not. No significant differences in percent body fat between methods were found at pre or post. The significance of main effects (method, time) and interactions (method x time) of the separate repeated measures ANOVAs for FM and FFM mirrored the results from the percent body fat analysis (small *p* value differences with the significance of main effects and the interaction effect from the percent body fat analysis remaining the same for the FM and FFM analyses).

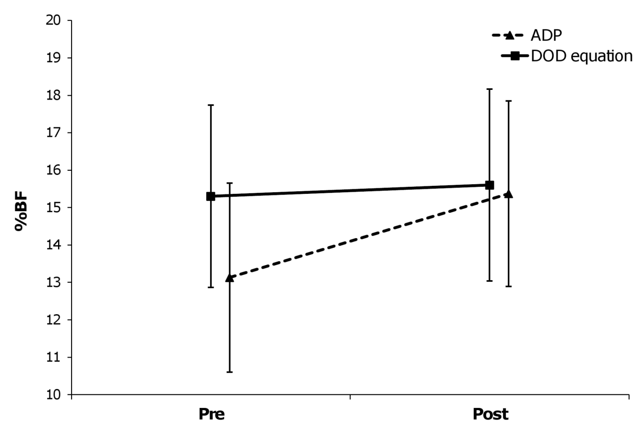

Figure 1. Interaction plot with 95% confidence limits for the change in percent body fat (%BF) estimated by air-displacement plethysmography (ADP) and the Department of Defense (DOD) prediction equation.

Although correlations for percent body fat, FM, and FFM were significant between ADP and the DOD equation at pre ($r = 0.47$, 0.61, and 0.82, respectively) and post ($r = 0.49$, 0.61, and 0.82, respectively), correlations for change in percent body fat, FM, and FFM between methods were weak and non-significant (r = 0.16, 0.26, and -0.05, respectively). Scatterplots with fitted regression lines contrasting changes in percent body fat, FM, and FFM for ADP and the DOD equation are presented in Figure 2. Both the slope and intercept significantly differed from the line of identity for the regressions modeling changes in percent body fat (p < .001 and p = 0.001, respectively) and FM (p = .0001 and p = 0.001, respectively) from ADP and the DOD equation. Only the slope significantly differed from the line of identity in the regression modeling changes in FFM (p < 0.001) from ADP and the DOD equation.

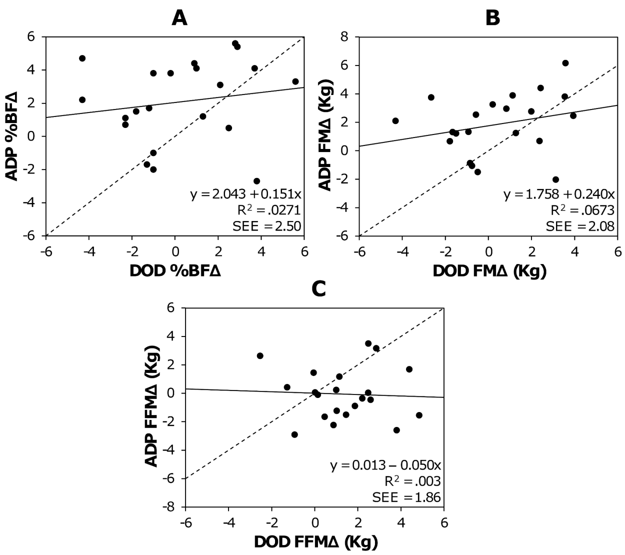

Figure 2. Scatterplots modeling the percent body fat change (%BFΔ; panel A), fat mass change (FMΔ; panel B) and fat-free mass change (FFMΔ; panel C) between air-displacement plethysmography (ADP) and the Department of Defense (DOD) prediction equation. The dashed line in each panel represents the line of identity (y=x). SEE = standard error of estimate.

Bland-Altman plots contrasting changes in percent body fat between ADP and the DOD equation are presented in Figure 3. For percent body fat, FM, and FFM, there was no discernable systematic pattern. However, the plots indicated a general underestimation by the DOD equation for changes in percent body fat and FM and an overestimation of FFM changes. In addition, two observations for the percent body fat plot (9.5% of observations) fell outside of the 95% limits of agreement.

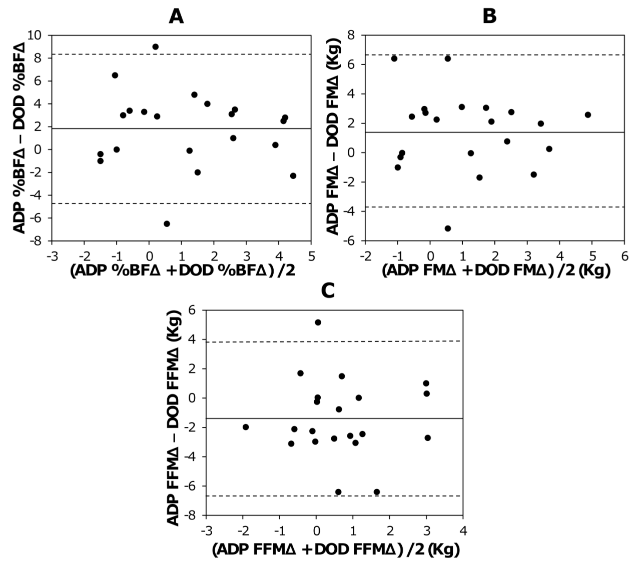

Figure 3. Bland-Altman plots with mean bias line (solid line) and 95% limits of agreements (dashed lines) contrasting body composition measures estimated by air-displacement plethysmography (ADP) and the Department of Defense (DOD) prediction equation for percent body fat change (%BFΔ; panel A), fat mass change (FMΔ; panel B), and fat-free mass change (FFMΔ; panel C).

DISCUSSION

To the authors' knowledge, this is the first investigation to prospectively track body composition among Army ROTC cadets in order to assess the validity of the DOD equation for males to detect body composition changes. Significant gains in body mass and BMI were observed among cadets during the 9 month follow-up. Although not statistically significant, findings at both pre and post time points indicated that the DOD equation overestimated percent body fat and FM, while underestimating FFM in comparison to ADP. Results also indicated that the DOD equation could not adequately detect body composition changes. Although changes in body mass and percent body fat were relatively small in this investigation (+1.8 Kg body mass, +2.1 percent body fat, respectively), such a change could certainly have substantial impacts on an individual's military standing (e.g., enrollment in a weight control program, denied promotion, etc.).

Findings from this investigation are in agreement with previous work which demonstrated that circumference-based prediction equations cannot adequately detect body composition changes among women (12). A previous investigation of body composition changes among men during an 8-week Army Ranger training course reported a mean abdominal circumference decrease of 10 cm in conjunction with a 8.5% reduction in percent body fat measured by DEXA (10). Although no circumference-based body composition prediction equations were used to estimate percent body fat changes in the Fried et al. (10) investigation, such a large decrease in abdominal circumference would have substantially affected percent body fat change estimates using a circumference-based technique. Interestingly, the significant percent body fat gain found among this sample (+ 2.1%) was only accompanied by a non-significant abdominal circumference increase of 0.6 cm (≈ ¼ inch), which had little effect on percent body fat change estimated by the DOD equation. Despite the shortfalls of comparing studies where body composition tracked in different directions, findings from this investigation suggest that changes in abdominal circumference may not adequately reflect body composition changes in men when implemented into the DOD equation.

A notable finding from this investigation was the 1.8 Kg body mass gain and 2.1% increase in percent body fat from pre to post among study participants. This unfavorable body composition change occurred despite Army ROTC cadets' requirement for mandatory physical training three times per week. However, Army ROTC cadets are a subpopulation of American college students, and previous literature has demonstrated that body mass and percent body fat tend to increase among college students during their academic careers (2, 7, 16, 19, 27, 30, 31, 39). Whether or not the FM gain observed during this study was due to insufficient amounts of physical activity or an increased energy intake cannot be ascertained as neither physical activity nor dietary intake were tracked during the follow-up period.

Several limitations of this study are worth noting. First, the choice to use the 2-compartment ADP approach as the criterion measure of body composition must be acknowledged. Although several investigations have shown ADP to underestimate percent body fat in adults when compared to DEXA and more lab intensive 4-compartment methods (9, 18, 32), its reliability and validity in assessing body composition has been demonstrated across a variety of populations, including adults (1, 5, 13, 21, 28), college aged males and females (4, 20, 25, 26), and overweight or obese adults (13). Moreover, ADP has been shown to track group changes in body composition equally as well as DEXA (23, 24, 40), and more recently ADP has been used as a criterion measure against other predictive models (29). Another limitation of this study was the choice to use predicted TGV while measuring body composition with ADP. Although, McCrory, Molé, Gomez, Dewey, and Bernauer (22) recommended that TGV be measured when assessing body composition with ADP, their research demonstrated that using predicted TGV was acceptable as predicted and measured TGV were not significantly different when making group mean comparisons. In addition, previous research has demonstrated that ADP and DEXA track group changes in body composition similarly when predicted TGV is used in ADP calculations (23). Another potential limitation includes the small sample size of the current study (n = 21). However, significant differences were found between ADP and DOD results, with post-hoc analyses indicating that repeated-measures ANOVA results for percent body fat, FM, and FFM achieved > 65% power to detect significant method by time interaction effects. Lastly, the sample was fairly homogenous (e.g., Caucasian males), and therefore, these results should not be generalized to other demographic groups.

This study provides further evidence questioning the use of circumference-based methods for assessing body composition. Before the body composition assessment protocol outlined in DOD 1308.3 was adopted, the Army (38), Navy (14), and Marine Corps (41) used their own prediction equations to assess percent body fat in males. Despite differences in the specific measurement and rounding procedures for these prediction equations, all of them relied on measurements of abdominal and neck circumference, while only the Army and Navy equations accounted for participant height. Previous research demonstrated that these equations produce similar results when estimating percent body fat (11). However, the lack of percent body fat change predicted by the DOD equation in this study raises questions about the validity of circumference-based assessments in tracking body composition changes, regardless of the specific equation used.

In conclusion, findings from this study suggest that the DOD equation for males does not adequately detect changes in body composition following a small body mass gain (≈ 2 Kg) in comparison to ADP. Although circumference-based prediction equations offer a quick and relatively non-invasive option for assessing body composition, they are of limited use if they cannot adequately detect changes in body composition. Further research is needed to identify field-based methods and/or techniques which are easy to implement and provide individually accurate estimates that can still adequately detect changes in body composition.

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