Validity and Reliability of Bioelectrical Impedance Analysis and Skinfold Thickness in Predicting Body Fat in Military Personnel

Anders Aandstad, MSc*†; Kristian Holtberget, MSc†; Rune Hageberg, MSc*; Ingar Holme, PhD†; Sigmund A. Anderssen, PhD†

ABSTRACT Previous studies show that body composition is related to injury risk and physical performance in soldiers. Thus, valid methods for measuring body composition in military personnel are needed. The frequently used body mass index method is not a valid measure of body composition in soldiers, but reliability and validity of alternative field methods are less investigated in military personnel. Thus, we carried out test and retest of skinfold (SKF), single frequency bioelectrical impedance analysis (SF-BIA), and multifrequency bioelectrical impedance analysis measurements in 65 male and female soldiers. Several validated equations were used to predict percent body fat from these methods. Dual-energy X-ray absorptiometry was also measured, and acted as the criterion method. Results showed that SF-BIA was the most reliable method in both genders. In women, SF-BIA was also the most valid method, whereas SKF or a combination of SKF and SF-BIA produced the highest validity in men. Reliability and validity varied substantially among the equations examined. The best methods and equations produced test–retest 95% limits of agreement below ±1% points, whereas the corresponding validity figures were ±3.5% points. Each investigator and practitioner must consider whether such measurement errors are acceptable for its specific use.

INTRODUCTION

A favorable body composition has been shown to be related to lower injury risk[1] and higher physical performance[2] in military personnel. Consequently, body composition is often evaluated in individuals before selection for military service and education. In-service evaluation of soldiers' body composition could also be relevant, because military service may well alter body composition, as seen from basic military training,[3] shorter intense military training courses,[4] or from international missions.[5] To optimize selection of prospective soldiers, and for precise in-service evaluation of soldiers' occupational readiness, health and nutritional status, reliable and valid body composition test methods should be applied to the individual soldier.

Body mass index (BMI) is used by some military systems when screening and selecting prospective soldiers.[6,7] Although BMI is a quick and easy proxy for body composition, it might be inaccurate on the individual level.[8] One of the main problems of using BMI is that it does not differentiate between muscle mass and fat mass, i.e., an athletic person with high levels of muscle mass might be classified as overweight. Thus, alternative methods for assessing body composition in military personnel should be evaluated.

*Department of Norwegian School of Sport Sciences-Defence Institute, The Norwegian Defence University College, P.O. Box 4014, Ullevaal Stadion, N-0806 Oslo, Norway.

†Department of Sports Medicine, Norwegian School of Sport Sciences, P.O. Box 4014, Ullevaal Stadion, N-0806 Oslo, Norway.

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Underwater weighing, hydrometry, dual-energy X-ray absorptiometry (DXA) and magnetic resonance imaging are among the body composition methods considered valid and often referred to as reference methods.[9,10] Such laboratory methods are time consuming, expensive, and not available for most military units. Thus, quicker and cheaper field methods are necessary for military settings. Skinfold (SKF) measurements and bioelectrical impedance analysis (BIA) might be two such alternative field methods for use on soldiers. The SKF method is based on the principle that there is a relationship between subcutaneous body fat (SKF thickness) and total body fat.[11] Measurement of SKF thickness at standardized anthropometrical sites is used to predict body density (BD), from which fat-free mass (FFM) or percent body fat (% BF) can be calculated using one of the many available prediction equations. The BIA method is based on the principle that electric current flows at different rates through the body depending on its composition.[12] The impedance measures (resistance, R and reactance, Xc) are used to predict total body water, FFM, or % BF from various equations. The BIA method uses either a single-frequency bioelectrical impedance analysis (SF-BIA) or a multifrequency bioelectrical impedance analysis (MF-BIA) instrument to measure body composition.[13]

Validity and reliability of SKF and BIA as tools for evaluating body composition have been frequently studied, but with divergent conclusions.[14] This might be because of the use of different reference methods, prediction equations, study populations, and statistical methods. Furthermore, it has been suggested that a sufficient variety of prediction equations has already been established, and that future studies should focus on cross validating existing equations on the specific population of interest.[15] For military populations, we have identified few studies published within the three last decades in which SKF and/or BIA methods have been validated against an acknowledged reference method. Kremer et al[16] found that validity of an SF-BIA device was not superior to a circumference method for predicting % BF in U.S. Air Force members. In a second study, Lintsi et al[17] predicted % BF in male conscripts and found a higher correlation coefficient for SKF against DXA compared to hand-to-hand SF-BIA against DXA. In addition, Friedl et al[3] found that selected SKF and circumference-based equations performed equally well in terms of validity in female soldiers, but that none of the equations were very accurate in detecting change in % BF (sensitivity). Studies on reliability of body composition field methods in military personnel seem to be even scarce.

Thus, the aim of this study has been to examine test–retest reliability and criterion-related validity of the SKF method, the SF-BIA method, a combined SF-BIA and SKF method, and the MF-BIA method in predicting % BF in male and female soldiers.

METHODS

Study Design and Ethics

Reliability of SKF and BIA measurements was evaluated in a test–retest design, whereas validity of SKF and BIA to predict % BF was evaluated by comparisons to the reference method DXA. The study was approved by the Regional Committee for Medical and Health Research Ethics and the Norwegian Social Science Data Services. Subjects volunteered to participate by giving their written consent after receiving written and oral information about the study.

Subjects

All first-year military cadets (39 men and 6 women) at the Royal Norwegian Air Force Academy volunteered for the study. In addition, 20 female military recruits and officers from Ørland Main Air Station gave consent to participate. Mean age (±SD and range) for the 39 men and 26 women was 22 ± 2 (19 – 27) and 21 ± 4 (18 – 30) years, respectively. All subjects were of Caucasian origin.

Measurements

All data were collected within three consecutive days for each subject. Twenty-four to 48 hours were allocated between test and retest measurements. The DXA scans were conducted at St. Olavs Hospital in Trondheim by trained staff. SKF and BIA measurements were administered locally at the military bases by three researchers (A.Aa, K.H, and R.H), each responsible for the same measurements during all data gathering. Data were collected in the morning from 7:00 a.m. until noon. Before all measurements, the subjects followed a standardization strategy that included ≥8 hours of fasting, ≥8 hours of no physical training, and ≥2 hours of no coffee or smoking. The subjects were allowed to drink water ad libitum before testing. Five of the women participated in the study during menstrual cycle. Temperature during all BIA and SKF measurements was between 19 and 21°C.

Height and body weight (BW) were measured with a combined digital scale and stadiometer (Seca model 708; Seca GmbH, Hamburg, Germany) to the nearest 0.1 kg and 5 mm, respectively. As subjects were measured wearing T-shirt and shorts, 0.3 kg was subtracted from the measured BW. The scale was calibrated with 40 to 80 kg of weight plates (Eleiko Sport AB, Halmstad, Sweden) before the test period.

DXA scans were performed on a Hologic Discovery A (Hologic, Bedford, Massachusetts) using the auto whole-body fan-beam mode with results analyzed using software version 12.7.3.1:3. Two days after the first scan, 12 randomly chosen cadets (9 men and 3 women) were re-scanned to investigate DXA test–retest reliability.

The RJL Quantum II (RJL Systems, Clinton Township, Michigan) was used to measure SF-BIA (50 kHz). The BIA device was calibrated once a day with a 500 ohm (Ω) test resistor. Testing was carried out as explained elsewhere,[18] and according to manufacturer instructions. FFM was calculated according to the equations given in Table I. Percent BF was then calculated as follows: $\% \text{ BF} = ([\text{BW} - \text{FFM}]/\text{BW}) \times 100$.

The InBody 720 (Biospace Co., Seoul, Korea) was used to measure MF-BIA (1–1000 kHz). Testing was conducted according to manufacturer instructions. The subject stepped on the foot electrodes barefoot and stood still until BW was measured (BW subtracted by 0.3 kg because subjects wore shorts and T-shirt). The subject grasped the hand electrode cables, and gently held on to the thumb electrode and the palm electrode. Hands were held ~15° away from the body, until measurements were completed. The inbuilt software was used to calculate % BF and other body composition values.

SKF thickness was measured with a Harpenden caliper (John Bull, British Indicators Ltd., West Sussex, UK) at seven sites for men and six sites for women (Table II). Anatomical location of the sites was according to Heyward and Wagner[33] and Lohman et al,[34] and always on the right side of the body. The sites were marked with a nonpermanent marking pen, so that the sites had to be relocated for the retest. Two measurements were taken at each site. If the second measure differed by more than 0.2 mm from the first reading, a third measure was taken. The average of the two closest measurements was recorded. The equations presented in Table I were used to calculate BD or % BF. The Siri equation was used to calculate % BF from BD: $\% \text{ BF} = (4.95/\text{BD} - 4.5) \times 100$.

Selection of Prediction Equations

Numerous equations exist for predicting body composition from SKF and SF-BIA measurements. We have only included equations developed and validated on populations similar to ours (pertaining to age, gender, ethnicity, and a normal/athletic body composition). In addition, our SKF equations depend on

TABLE I. Selected Equations for Predicting BD, FFM or % BF From SKF and/or BIA Measurements in Adult Men (m) and Women (w)

Method	Prediction Equation
SKF	
Durnin and Womersley[19] (m)	$BD = 1.1765 - 0.0744 \cdot \log \Sigma 1$
Durnin and Womersley[19] (w)	$BD = 1.1567 - 0.0717 \cdot \log \Sigma 1$
Jackson and Pollock[20] (m)	$BD = 1.1125025 - 0.0013125 \cdot \Sigma 2 + 0.0000055 \cdot \Sigma 2^2 - 0.0002440 \cdot A$
Jackson and Pollock[20] (w)	$BD = 1.089733 - 0.0009245 \cdot \Sigma 3 + 0.0000025 \cdot \Sigma 3^2 - 0.0000979 \cdot A$
Jackson et al[21] (m)	$BF = 0.2568 \cdot \Sigma 4 - 0.0004 \cdot \Sigma 4^2 + 4.8647$
Jackson et al[21] (w)	$BF = 0.4446 \cdot \Sigma 4 - 0.0012 \cdot \Sigma 4^2 + 4.3387$
Lohman[11] (m)	$BD = 1.0982 - 0.000815 \cdot \Sigma 5 + 0.00000084 \cdot \Sigma 5^2$
Slaughter et al[22] (m)	$BF = 1.21 \cdot \Sigma 6 - 0.008 \cdot \Sigma 6^2 - 5.5$
Slaughter et al[22] (w)	$BF = 1.33 \cdot \Sigma 6 - 0.013 \cdot \Sigma 6^2 - 2.5$
SF-BIA	
Deurenberg et al[23] (m + w)	$FFM = 0.340 \cdot H^2/R - 0.127 \cdot A + 0.273 \cdot BW + 4.56 \cdot G1 + 0.1534 \cdot H - 12.44$
Gray et al[24] (m)	$FFM = 0.00139 \cdot H^2 - 0.0801 \cdot R + 0.187 \cdot BW + 39.830$
Gray et al[24] (w)	$FFM = 0.00151 \cdot H^2 - 0.0344 \cdot R + 0.140 \cdot BW - 0.158 \cdot A + 20.387$
Kotler et al[25] (m)	$FFM = 0.50 \cdot (H^{1.48}/R^{0.55}) \cdot (1.0/1.21) + 0.42 \cdot BW + 0.49$
Kotler et al[25] (w)	$FFM = 0.88 \cdot (H^{1.97}/R^{0.49}) \cdot (1.0/22.22) + 0.081 \cdot BW + 0.07$
Kyle et al[26] (m + w)	$FFM = 0.518 \cdot H^2/R + 0.231 \cdot BW + 0.130 \cdot Xc + 4.229 \cdot G1 - 4.104$
Lohman[15] (m)	$FFM = 0.485 \cdot H^2/R + 0.338 \cdot BW + 5.32$
Lohman[15] (w)	$FFM = 0.476 \cdot H^2/R + 0.295 \cdot BW + 5.49$
Lukaski et al[27] (m)	$FFM = 0.827 \cdot H^2/R + 5.214$
Lukaski et al[27] (w)	$FFM = 0.821 \cdot H^2/R + 4.917$
Segal et al GEN [28] (m)	$FFM = 0.00132 \cdot H^2 - 0.04394 \cdot R + 0.30520 \cdot BW - 0.16760 \cdot A + 22.66827$
Segal et al GEN [28] (w)	$FFM = 0.00108 \cdot H^2 - 0.02090 \cdot R + 0.23199 \cdot BW - 0.06777 \cdot A + 14.59453$
Segal et al FSE [28] (m)	$FFM = 0.0006636 \cdot H^2 - 0.02117 \cdot R + 0.62854 \cdot BW - 0.12380 \cdot A + 9.33285$
Segal et al FSE [28] (w)	$FFM = 0.00064602 \cdot H^2 - 0.01397 \cdot R + 0.42087 \cdot BW + 10.43485$
Sun et al[29] (m)	$FFM = 0.65 \cdot H^2/R + 0.26 \cdot BW + 0.02 \cdot R - 10.68$
Sun et al[29] (w)	$FFM = 0.69 \cdot H^2/R + 0.17 \cdot BW + 0.02 \cdot R - 9.53$
van Loan et al[30] (m + w)	$FFM = 0.51 \cdot H^2/R + 0.33 \cdot BW + 1.69 \cdot G2 + 3.66$
SKF and SF-BIA	
Guo et al[31] (m)	$BF = -0.2790 \cdot H^2/R + 0.6316 \cdot T + 0.3464 \cdot BW + 1.5034$
Yannakoulia et al[32] (w)	$FFM = 0.391 \cdot BW + 0.168 \cdot H - 0.253 \cdot T + 0.144 \cdot H^2/R - 9.49$
MF-BIA	
InBody 720 equation (m + w)	Unknown, in-built manufacturer equation

BD, body density; BF, percent body fat; FFM, fat-free mass; GEN, generalized equation; FSE, fatness specific equation; A, age (years); H, height (cm); R, resistance (ohm); Xc, reactance (ohm); BW, body weight (kg); G1, gender (man = 1, woman = 0); G2, gender (man = 1, woman = −1); T, triceps SKF (mm); Σ1, sum of triceps + biceps + subscapular + suprailiac SKF (mm); Σ2, sum of chest + triceps + subscapular SKF (mm); Σ3, sum of triceps + suprailiac + abdominal SKF (mm); Σ4, sum of triceps + suprailiac + thigh SKF (mm); Σ5, sum of triceps + abdominal + subscapular SKF (mm); Σ6, sum of triceps + subscapular SKF (mm).

a maximum of four SKF sites and the equations are "generalized."[20] Our selection of SF-BIA equations is based on reviews in this field made by Kyle et al[35] and Houtkooper et al,[36] including only prediction equations developed using a traditional 50 kHz device. We have also included two studies that validated equations combining SF-BIA and a one-site SKF measure. The prediction equation for % BF from the MF-BIA device is not known, because it is not released by the manufacturer. Thus, results from the MF-BIA measurements are based on the preset equation for this device.

Statistical Analysis

Test–retest reliability was examined using mean difference ±95% limits of agreement (LoA) including Bland–Altman plots and intraclass correlation coefficient (ICC 3,1–single measures) with 95% confidence interval (CI). Validity was examined using the same statistical methods as for the reliability analysis, in addition to Pearson correlation coefficient (*r*). Data from the first tests (no retest data) were used to evaluate validity. Differences between test–retest measurements, and among % BF measured from DXA and the various field methods, were analyzed with a paired sample *t* test. Differences between men and women were analyzed with an independent sample *t* test. All statistical analyses were performed in SPSS (version 18.0; IBM Corporation, Armonk, New York), except for the LoA analysis for which MedCalc (version 12.1.4; MedCalc Software bvba, Ostend, Belgium) was used. A probability (p) of <0.05 was considered statistically significant.

RESULTS

Descriptive Results

Descriptive characteristics for the participating subjects in test and retest are shown in Table II. Men were significantly different from women in all measured values at first test, except for BMI ($p = 0.06$) and Xc ($p = 0.10$). Mean DXA measured % BF were 10% points lower in men compared to

TABLE II. Descriptive Characteristics of Body Composition Measurements at Test and Retest. Results Presented as Means (SD)

Variable	Men (n = 39) Test	Men (n = 39) Retest	Women (n = 26) Test	Women (n = 26) Retest
Height (cm)	183.0 (6.5)	183.0 (6.5)	167.0 (6.0)	167.0 (5.5)
Body Weight (kg)	80.3 (10.2)	80.1 (10.2)*	63.1 (8.4)	63.1 (8.4)
BMI (kg m^{-2})	24.0 (2.5)	23.9 (2.5)	22.7 (2.9)	22.7 (2.9)
SKF				
Triceps (mm)	11.3 (4.1)	11.7 (4.3)*	19.6 (4.9)	19.5 (4.2)
Biceps (mm)	5.1 (1.7)	5.5 (2.0)*	11.6 (4.7)	11.4 (3.9)
Abdominal (mm)	18.8 (6.3)	20.5 (7.5)*	27.5 (7.4)	27.7 (7.1)
Suprailiac (mm)	16.7 (4.9)	19.6 (7.4)*	23.3 (9.6)	22.6 (8.2)
Thigh (mm)	13.8 (5.6)	14.6 (5.9)*	28.0 (8.8)	28.0 (7.5)
Subscapular (mm)	11.0 (2.9)	11.6 (3.3)*	14.1 (6.5)	14.1 6.8)
Chest (mm)	6.5 (2.1)	6.6 (2.1)	N/A	N/A
SF-BIA				
Resistance, R (Ω)	467 (45)	467 (45)	563 (58)	565 (57)
Reactance, Xc (Ω)	65 (6)	65 (6)	67 (6)	67 (7)
MF-BIA				
Body Weight (kg)	80.3 (10.3)	80.1 (10.2)*	63.3 (8.4)	63.3 (8.4)
Fat Free Mass (kg)	69.2 (7.5)	69.0 (7.5)	48.0 (4.9)	48.1 (4.7)
Body Fat (kg)	11.1 (4.4)	11.1 (4.6)	15.3 (5.8)	15.3 (5.9)
Body Fat (%)	13.5 (4.5)	13.6 (4.8)	23.7 (6.4)	23.5 (6.5)
DXA[a]				
Body Weight (kg)	81.1 (10.2)	80.7 (11.8)	64.3 (8.6)	64.9 (7.6)*
Fat Free Mass (kg)	68.2 (7.4)	68.2 (8.2)	47.6 (4.8)	48.5 (2.6)
Bone Mineral Density (g cm^{-2})	1.20 (0.09)	1.17 (0.04)	1.11 (0.07)	1.16 (0.04)
Body Fat (kg)	12.9 (4.1)	12.5 (4.4)	16.7 (5.0)	16.4 (6.7)
Body Fat (%)	15.6 (3.7)	15.1 (3.4)	25.6 (4.7)	24.8 (7.5)

N/A, not available. *$p < 0.05$ between test and retest. [a]DXA retest sample consists of only 9 men and 3 women.

women. In men, six out of seven SKF sites were measured to be significantly thicker at retest compared to the first test.

Reliability

Reliability statistics of the different methods and equations for men and women are presented in Table III and IV, respectively.

In men, the average test–retest measurement error (95% LoA) was ±2.5% points BF in the five SKF equations, whereas the corresponding figure was ±2.0% points for the ten SF-BIA equations. The LoA for the combined SKF & SF-BIA equation and the MF-BIA device was ±1.4% and ±2.3%, respectively. Among all methods and equations applied on men, the smallest LoA was seen for the SF-BIA fatness specific equation (FSE) by Segal et al (Fig. 1A). All SKF equations predicted % BF to be significantly higher in the retest compared to the first test.

In women, the average test–retest LoA for % BF was ±3.2% points in the 4 SKF equations, whereas the corresponding figure was ±1.7% points for the 10 SF-BIA equations. The LoA for the combined SKF and SF-BIA equation and the MF-BIA device was ±1.8% and ±2.6%, respectively. The smallest LoA was seen for the SF-BIA Segal et al FSE (Fig. 1B).

Figure 2 shows test–retest measurements for DXA. Mean difference ±95% LoA was −0.1 ± 0.8% BF, whereas ICC (95% CI) was 1.00 (0.99–1.00) for DXA test–retest.

Validity

Tables V and VI show validity statistics of the different methods and equations for men and women, respectively.

In men, the average LoA for predicted % BF in the five SKF equations (when compared to DXA) was ±4.2% points, whereas the corresponding figure was ±5.4% points for the ten SF-BIA equations. The MF-BIA device and the combined SF-BIA and SKF equation produced smaller LoA and higher r and ICC against DXA, compared to all SF-BIA equations. Among all methods and equations, the smallest LoA was observed for the SKF equation by Jackson et al (Fig. 1C).

In women, the average LoA for predicted % BF in the four SKF equations (when compared to DXA) was ±5.7% points, whereas the corresponding figure was ±5.6% points for the ten SF-BIA equations. The MF-BIA device and the combined SF-BIA and SKF equation produced a LoA comparable to the average SKF and SF-BIA measurement error. Among all methods and equations, the SF-BIA equation by Kyle et al produced the smallest LoA, but the equation significantly overestimated % BF by 2.5% points (Fig. 1D).

DISCUSSION

This study sought to evaluate reliability and validity of body composition field methods based on SKF and BIA in predicting % BF in military personnel. The data revealed that reliability and validity varied substantially among equations.

TABLE III. Reliability Statistics (Test–Retest) for Predicted Percent Body Fat From SKF and BIA Measurements in 39 men. Ranked According to 95% LoA Within Each Method Category

Method	Mean Difference ± 95% LoA (% BF)	ICC (95% CI)
SKF		
Jackson and Pollock[20]	−0.4 ± 1.3*	0.98 (0.96– 0.99)
Slaughter et al[22]	−0.8 ± 2.0*	0.98 (0.97– 0.99)
Lohman[11]	−0.9 ± 2.6*	0.95 (0.90– 0.97)
Jackson et al[21]	−1.2 ± 3.1*	0.88 (0.78– 0.94)
Durnin and Womersley[19]	−1.4 ± 3.5*	0.91 (0.84– 0.95)
SF-BIA		
Segal et al FSE [28]	0 ± 0.7	0.99 (0.98– 0.99)
Kotler et al[25]	0 ± 1.1	0.99 (0.98– 0.99)
Segal et al GEN[28]	0 ± 1.4	0.99 (0.98– 0.99)
Deurenberg et al[23]	0 ± 1.5	0.99 (0.97– 0.99)
Lohman[15]	0 ± 2.1	0.97 (0.94– 0.98)
Van Loan et al[30]	0 ± 2.2	0.97 (0.94– 0.98)
Kyle et al[26]	0.1 ± 2.2	0.97 (0.95– 0.99)
Sun et al[29]	0 ± 2.3	0.97 (0.94– 0.98)
Gray et al[24]	0 ± 2.4	0.97 (0.95– 0.99)
Lukaski et al[27]	0 ± 3.6	0.96 (0.93– 0.98)
SKF and SF-BIA		
Guo et al[31]	−0.3 ± 1.4*	0.99 (0.98– 0.99)
MF-BIA		
InBody 720 equation	−0.1 ± 2.3	0.97 (0.94– 0.98)

GEN, generalized equation; FSE, fatness specific equation. *$p < 0.05$ for mean difference between test and retest.

TABLE IV. Reliability Statistics (Test–Retest) for Predicted Percent Body Fat From SKF and BIA Measurements in 26 Women. Ranked According to 95% LoA Within Each Method Category

Method	Mean Difference ± 95% LoA (% BF)	ICC (95% CI)
SKF		
Slaughter et al[22]	−0.1 ± 2.0	0.96 (0.90– 0.98)
Durnin and Womersley[19]	0.1 ± 3.2	0.94 (0.87– 0.97)
Jackson and Pollock[20]	0.1 ± 3.5	0.93 (0.86– 0.97)
Jackson et al[21]	0.1 ± 4.2	0.92 (0.83– 0.96)
SF-BIA		
Segal et al FSE[28]	−0.1 ± 0.8	0.99 (0.99– 1.00)
Segal et al GEN[28]	−0.1 ± 1.2	0.99 (0.99– 1.00)
Deurenberg et al[23]	−0.1 ± 1.3	0.99 (0.98– 1.00)
Lohman[15]	−0.2 ± 1.6	0.99 (0.97– 0.99)
Sun et al[29]	−0.2 ± 1.7	0.99 (0.98– 1.00)
Van Loan et al[30]	−0.2 ± 1.7	0.98 (0.96– 0.99)
Gray et al[24]	−0.1 ± 1.8	0.99 (0.98– 1.00)
Kotler et al[25]	−0.1 ± 1.8	0.99 (0.98– 1.00)
Kyle et al[26]	−0.1 ± 2.0	0.98 (0.96– 0.99)
Lukaski et al[27]	−0.3 ± 2.8	0.98 (0.96– 0.99)
SKF and SF-BIA		
Yannakoulia et al[32]	0 ± 1.8	0.99 (0.97– 0.99)
MF-BIA		
InBody 720 equation	0.2 ± 2.6	0.98 (0.95– 0.99)

GEN, generalized equation; FSE, fatness specific equation. *$p < 0.05$ for mean difference between test and retest.

SKF Method

Reliability of the SKF method was generally slightly lower (wider LoA and lower ICC) compared to the other methods investigated. In men, validity of the SKF method was generally higher (smaller LoA, higher ICC and *r*) than the SF-BIA method, whereas the opposite was evident for women. Validity of the SKF method was comparable to that observed for the combined SKF and SF-BIA and the MF-BIA method.

Among the SKF equations for men, the Jackson and Pollock equation showed the smallest test–retest measurement error (LoA), but also a large underestimation of % BF when compared to DXA. The Jackson et al equation demonstrated high validity, but lower reliability. Thus, in men, no SKF equation was clearly superior to the others when both reliability and validity are accounted for. In women, the equation by Slaughter et al demonstrated higher reliability compared to the other SKF equations. It was also the only equation that showed no mean difference in estimated % BF when compared to DXA. However, the Slaughter et al equation produced the lowest correlation (ICC and *r*) against DXA, and had the second widest LoA (±6.0%) for predicting % BF. Hence, similar to men, no single SKF equation for women was superior to the other equations on both reliability and validity.

Major advantages of the SKF method are that it uses a simple instrument, measurements can easily be carried out in the field, it is relatively quick, and it is resistant to fast changes in hydration status.[37,38] Conversely, a major drawback is that rather extensive training is needed to obtain reliable measurements.[10,38] In our male subjects, SKF thickness was measured to be significantly higher in all but one SKF sites during retest compared to the first test. Hence, all male SKF equations predicted % BF to be higher in the retest. This finding is most likely because of a systematic error made by the operator, and illustrates that accurate and precise SKF measurements might be difficult to obtain. All men were measured during the first week, whereas most women were measured during the second week. This might explain why the systematic error appeared only in data points for men. Thus, SKF reliability for the male subjects should be evaluated with some caution. Still, this study demonstrated that reliability for the SKF method was in accordance with previous data for both men and women.[39]

SF-BIA Method

Reliability of the SF-BIA method was generally higher compared to the SKF method. Most SF-BIA equations also showed higher reliability compared to the MF-BIA method. Among women, four SF-BIA equations produced smaller LoA (higher validity) for estimated % BF against DXA, when compared to all other methods and equations. On the contrary, most of the male SF-BIA equations produced wider LoA (lower validity) compared to other methods and equations investigated.

No single SF-BIA equation stood out as superior to all other equations when both reliability and validity were considered. Yet, for both men and women the Segal et al FSE produced the smallest test–retest LoA among all the methods

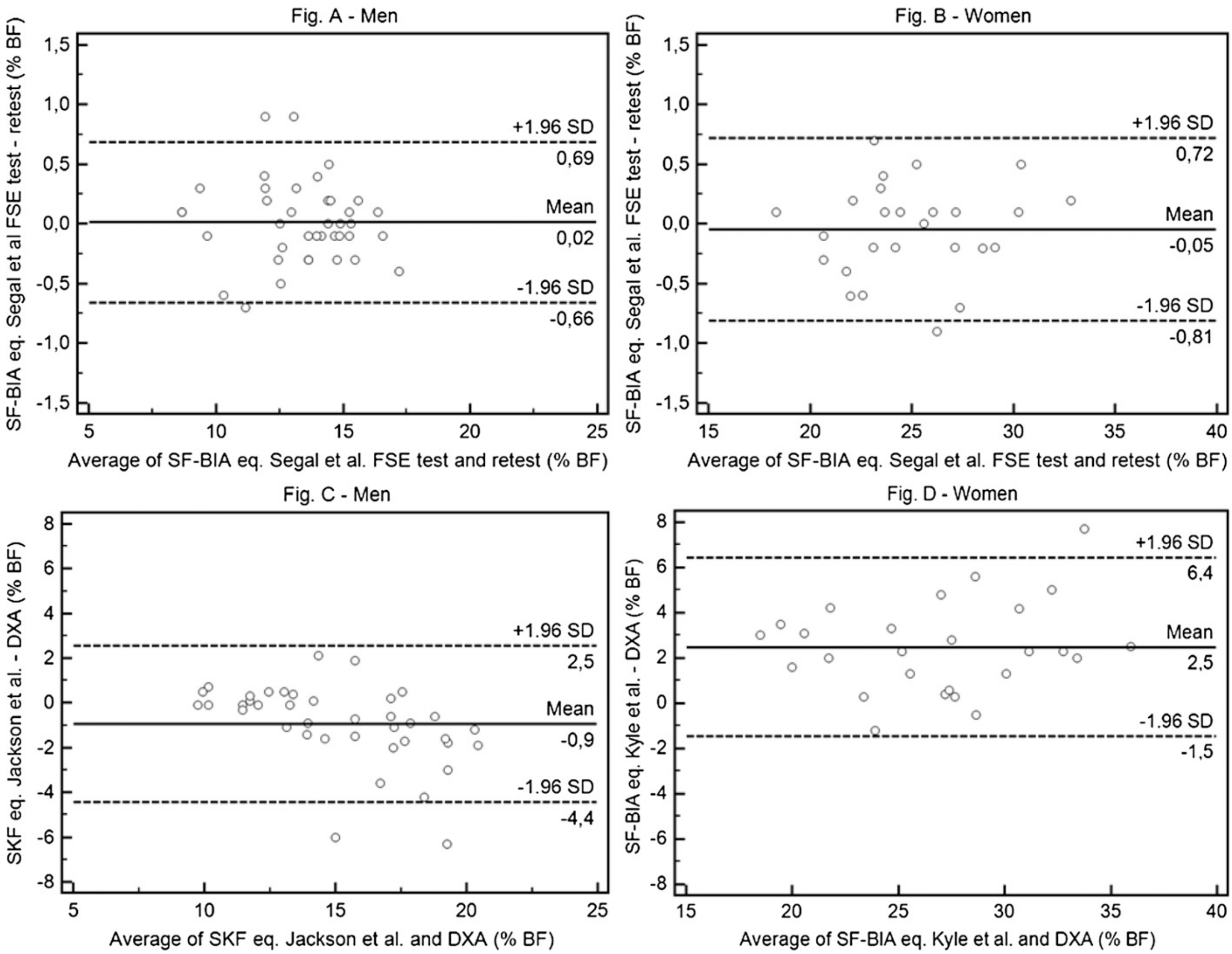

FIGURE 1. Bland–Altman plots with mean difference ± 95% LoA for reliability and validity of selected methods for predicting % BF. (A) Test–retest reliability of SF-BIA using equation by Segal et al (fatness specific equation [FSE]) in men. (B) Test–retest reliability of the SF-BIA using equation by Segal et al (FSE) in women. (C) Validity of SKF using equation by Jackson et al in men. (D) Validity of SF-BIA using equation by Kyle et al in women.

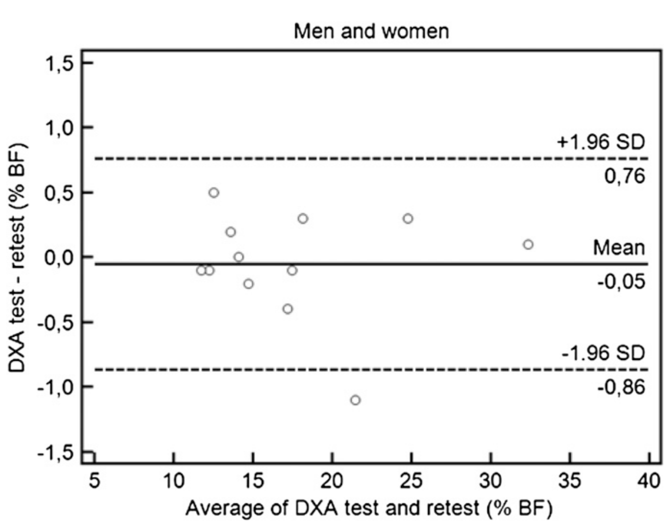

FIGURE 2. Bland–Altman plot with mean difference ± 95% LoA for % BF measured by DXA in first test and retest (*n* = 12).

and equations scrutinized. The Segal et al FSE is primarily developed for use among men and women below 20% BF and 30% BF, respectively.[28] Because most of our subjects demonstrated % BF values within these limits, this might be one of the reasons why this equation produced the smallest test–retest LoA.

Although the SF-BIA Segal et al FSE demonstrated the smallest test–retest LoA, other SF-BIA equations demonstrated higher validity. The Lohman equation (for men) showed no mean difference in estimated % BF compared to DXA, and relatively small LoA. The Lohman equation also produced small LoA against DXA in women, but % BF was underestimated by 1.9% points. Overall, the SF-BIA method (e.g., Lohman equation) might be recommended in female soldiers, because it scored high on both reliability and validity. Validity for the SF-BIA equations with the smallest LoA was comparable to previous findings by Williams and Bale.[40] The latter study demonstrated a slightly higher validity for the

TABLE V. Validity Statistics for Predicted Percent Body Fat From SKF and BIA Measurements Against Percent Body Fat Measured with DXA in 39 Men. Ranked According to 95% LoA Within Each Method Category

Method	Mean Difference ± 95% LoA (% BF)	ICC (95% CI)	Pearson *r*
SKF			
Jackson et al[21]	−0.9 ± 3.5*	0.85 (0.74– 0.92)	0.88
Durnin and Womersley[19]	3.4 ± 3.7*	0.87 (0.77– 0.93)	0.87
Lohman[11]	−1.3 ± 3.9*	0.86 (0.74– 0.92)	0.86
Jackson and Pollock[20]	−4.8 ± 4.8*	0.87 (0.76– 0. 93)	0.87
Slaughter et al[22]	1.6 ± 5.2*	0.82 (0.69– 0.90)	0.87
SF-BIA			
Kotler et al[25]	2.2 ± 4.4*	0.81 (0.66– 0.89)	0.81
Lohman[15]	−0.1 ± 4.7	0.82 (0.68– 0.90)	0.83
Kyle et al[26]	3.5 ± 4.7*	0.84 (0.72– 0.91)	0.87
Van Loan et al[30]	−1.6 ± 4.9*	0.81 (0.67– 0.90)	0.83
Segal et al FSE[28]	−2.2 ± 4.9*	0.66 (0.43– 0.80)	0.76
Deurenberg et al[23]	4.4 ± 5.1*	0.80 (0.64– 0.89)	0.81
Sun et al[29]	1.1 ± 5.2*	0.80 (0.66– 0.89)	0.83
Segal et al GEN[28]	0.3 ± 5.7	0.76 (0.59– 0.87)	0.78
Gray et al[24]	4.2 ± 5.9*	0.78 (0.62– 0.88)	0.83
Lukaski et al[27]	2.9 ± 8.5*	0.69 (0.48– 0.82)	0.82
SKF and SF-BIA			
Guo et al[31]	0.6 ± 3.6*	0.90 (0.82– 0.95)	0.92
MF-BIA			
InBody 720 equation	−2.1 ± 3.9*	0.89 (0.79– 0.94)	0.90

GEN, generalized equation; FSE, fatness specific equation. *$p < 0.05$ for mean difference between prediction equation and DXA.

TABLE VI. Validity Statistics for Predicted Percent Body Fat From SKF and BIA Measurements Against Percent Body Fat Measured With DXA in 26 Women. Ranked According to 95% LoA Within Each Method Category

Method	Mean Difference ± 95% LoA (% BF)	ICC (95% CI)	Pearson *r*
SKF			
Jackson and Pollock[20]	2.3 ± 4.7*	0.88 (0.75– 0.95)	0.88
Jackson et al[21]	3.6 ± 5.4*	0.86 (0.71– 0.93)	0.87
Slaughter et al[22]	0.4 ± 6.0	0.73 (0.49– 0.87)	0.77
Durnin and Womersley[19]	6.6 ± 6.6*	0.88 (0.75– 0.94)	0.88
SF-BIA			
Kyle et al[26]	2.5 ± 4.0*	0.92 (0.82– 0.96)	0.92
Lohman[15]	−1.9 ± 4.2*	0.90 (0.79– 0.96)	0.90
Van Loan et al[30]	−2.5 ± 4.2*	0.90 (0.78– 0.95)	0.90
Deurenberg et al[23]	3.2 ± 4.6*	0.88 (0.74– 0.94)	0.88
Segal et al FSE[28]	−0.7 ± 5.2	0.80 (0.60– 0.91)	0.84
Sun et al[29]	−0.5 ± 5.3	0.87 (0.74– 0.94)	0.89
Segal et al GEN[28]	0.8 ± 5.8	0.83 (0.66– 0.92)	0.84
Gray et al[24]	−3.2 ± 7.3*	0.80 (0.60– 0.91)	0.85
Kotler et al[25]	−2.1 ± 7.5*	0.80 (0.60– 0.90)	0.87
Lukaski et al[27]	0.9 ± 8.0	0.80 (0.60– 0.91)	0.90
SKF and SF-BIA			
Yannakoulia et al[32]	1.8 ± 5.3*	0.86 (0.71– 0.93)	0.86
MF-BIA			
InBody 720 equation	−1.9 ± 5.2*	0.89 (0.77– 0.95)	0.93

GEN, generalized equation; FSE, fatness specific equation. *$p < 0.05$ for mean difference between prediction equation and DXA.

SKF method compared to the SF-BIA method for both male and female athletes. However, Lukaski et al[27] found the opposite in a heterogeneous sample of adult men and women. Thus, although reliability generally seems to be somewhat higher for BIA methods compared to SKF methods,[38] no clear conclusion is given in the literature on whether BIA or SKF produce the highest validity.[10,15]

Our results showed clearly that picking the right SF-BIA equation is crucial, as measurement error varied substantially between different equations. As an example, three of the female SF-BIA equations produced a LoA of ≥ ±7% BF against DXA. If predicting % BF to be 20% in a woman using one of these equations, the investigator must account for that her true % BF is somewhere between 13 and 27% BF.

In most cases, such high measurement error is not acceptable, and other methods or equations should be used.

There are several advantages of the SF-BIA method. The method is quick, the instrument is relatively cheap to purchase and use, the instrument is small and mobile, it is easy to operate, and testing can be carried out without the subject undressing. The drawback is that the test conditions should be standardized to get normal hydration levels, which mean that dietary intake and physical exercise should be controlled before measurement.[12] Such standardization could be difficult to obtain in military settings.

Combined SF-BIA and SKF Method

Reliability of the combined SF-BIA & SKF method was generally higher compared to the other methods, although some SF-BIA equations produced smaller test–retest LoA in both men and women. In men, the Guo et al equation produced higher ICC and *r* against DXA compared to all other methods, and also the second smallest LoA. Hence, this equation seems to be a good option for male soldiers, because it scored high on both reliability and validity. However, in women, validity of the Yannakoulia et al equation was not higher than the other methods and equations.

One disadvantage of the combined method is that both SKF and BIA measurements must be obtained. Yannakoulia et al concluded that adding SKF to the SF-BIA equation only reduced the measurement error slightly, and actually recommended to not add the SKF measurement.[32] Yet, both the female and male equations are based on only one SKF site (triceps), which is a quick and relatively easy (low inter-tester variability[41]) site to measure. Thus, the combined method is probably faster and easier to carry out compared to traditional 4-sites SKF measurements. Other pros and cons of this method should be similar to those previously explained for SKF and SF-BIA.

MF-BIA Method

The MF-BIA method (InBody 720) produced wider test–retest LoA when compared to several SF-BIA and SKF equations. Validity of the MF-BIA device was higher than that observed for all SF-BIA equations in men, but not in women. The InBody 720 underestimated % BF against DXA by approximately 2% in both men and women. This is in line with previous findings by Völgyi et al.[42]

The InBody 720 is user friendly, both for the operator and the person tested. Within a few minutes, the machine displays results for several body composition factors, such as % BF, visceral fat, muscle balance between right/left side and upper/lower body, and total skeleton muscle mass. The latter is important in a performance/military context, but could also be calculated from the SF-BIA method.[43] Compared to the SF-BIA device, the InBody 720 is more expensive and less portable. In addition, it is not possible to use other algorithms than the one that is preset. As for the SF-BIA method, standardization of dietary intake and physical exercise is important.

Study Limitations

In validation studies, a basic assumption is that the reference method must be accurate and precise, so that the indirect method could be compared against "true" figures. However, there is no universally accepted "gold standard" methodology within body composition research.[10] DXA is a much used reference method in body composition validation studies, but has some limitations. The DXA algorithm assumes a constant hydration of the FFM, which is not always true.[29] In addition, different DXA machines and software might produce significantly different figures for the various body composition components.[44] Nevertheless, DXA is usually considered a reasonably precise whole-body method,[10] and a method that produces highly reliable measurements of BF.[44] The latter was verified through our own test–retest DXA measurements.

Our male SKF measurements were significantly higher at six out of seven sites during retest compared to the first test. As mentioned, this was probably because of a systematic error made by the operator. This fault does not only influence reliability but also validity for the male SKF measures. This systematic error exemplifies that SKF measurements could be difficult to obtain accurately, even among relatively experienced test leaders. This should be taken into account when selecting a body composition field method for use on soldiers.

A great number of prediction equations for estimating FFM and BF exist for both SF-BIA and SKF measurements. We have selected some of the most used equations, and equations that have been developed in similar populations as our soldiers. Still, we might have overlooked some equations that could have performed equally well, or better, compared to our selected equations.

Kremer et al[16] suggested that circumference-based equations predict % BF as accurately as BIA in military personnel. Our study examined only SKF and BIA out of several existing body composition field methods. Thus, we cannot determine whether other field methods could have performed better in estimating % BF in military personnel. Friedl et al[45] also recommended circumference measurements in large-scale military screenings, because it is an easier measurement for nontechnical users. The choice of a body composition field method should therefore not exclusively depend on measurement error obtained under more optimized research settings.

This study was conducted on soldiers with a normal/athletic body composition and with age ranging from 19 to 30 years. In addition, all subjects were of Caucasian origin. Because equations for SKF and BIA have been shown to be population specific,[15] our results should not be generalized to all type of military personnel, e.g., subjects that are older, less fit, or of a different ethnicity.

CONCLUSION

This study found that none of the body composition methods investigated was clearly superior to other methods, because the results varied according to gender, which equation was used, and whether the focus was on reliability versus validity. However, in women, some SF-BIA equations were both more reliable and valid (smaller LoA, higher ICC and *r*) than the other methods and equations. In male soldiers, we think the combined SKF and SF-BIA method (Guo et al equation) could be recommended in personnel with similar demographics to the study group, when both reliability and validity are considered. In all methods, a relatively large measurement error (wide LoA) against DXA must be accounted for at the individual level. Selection of an appropriate SKF or BIA equation to predict % BF is crucial, because both validity and reliability might vary greatly from one equation to another.

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