ORIGINAL ARTICLE

Body composition assessment in athletes with spinal cord injury: comparison of field methods with dual-energy X-ray absorptiometry

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Study design: Cross-sectional.

Objectives: To compare relative body fatness (%Fat) estimates from field methods (skinfold thickness measurement (SKF) and bioelectrical impedance analysis (BIA)) with measures by dual-energy X-ray absorptiometry (DXA).

Setting: University of Illinois, Urbana-Champaign, IL, USA.

Methods: Field methods used both three- and seven-site SKF prediction equations and BIA generalized, spinal cord injury (SCI)-specific and athlete-specific equations. DXA was used as the reference method. College-aged varsity athletes with SCI (women = 8, men = 8; time since injury 16.2 ± 5.7 years; injury level range T5–L5) were recruited.

Results: Mean BMI was 20.8 ± 2.6 and $22.5 \pm 2.1 \text{ kg m}^{-2}$, and mean DXA %Fat was 31.9 ± 3.8 and $20.6 \pm 8.4\%$, for women and men, respectively. All field methods under-predicted the %Fat when compared with DXA (ranges in mean differences: SKF women 2.9–8.2%, SKF men 6.9–12.4%; BIA women 0.5–3.9%, BIA men 0.3–7.0%). None of the field methods accurately predicted the %Fat compared with DXA (total error (TE): SKF women 7.4–12.1%, SKF men 8.4–15.2%; BIA women 5.1–9.3%, BIA men 6.7–10.7%). Of the SKF and BIA prediction equations, Evans *et al.*'s three-site SKF ($r = 0.95$, $P < 0.001$, standard error of the estimate (SEE) = 2.8 %Fat) prediction equation provided the best fit for this population.

Conclusion: Further studies with larger samples are necessary to develop appropriate prediction equations for field methods in the athletic SCI population.

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Introduction

The gold standard for body composition assessment is a multicompartiment model method that measures bone mineral and water minimally. Densitometry equipment is needed in the multicompartiment model; however, densitometry measurements have shown to result in wide individual variation when used to assess the relative body fat (%Fat) in populations with spinal cord injury (SCI).¹ The multicompartiment model is also costly and has high subject burden, and although dual-energy X-ray absorptiometry (DXA) is not a gold standard method, and may underestimate fat mass (FM) and overestimate fat-free mass (FFM) in comparison to the multicompartiment model,^{2,3} it has

become the commonly used method for assessing whole body composition.

DXA is used only in clinical settings and is not a feasible method in many situations and populations. Practitioners working with athletes need field methods using portable equipment that provide reliable results. Skinfold thickness measurements (SKF) and bioelectrical impedance analysis (BIA) are typically used in athletic populations.

Body-composition data are useful for monitoring the effectiveness of a training or dietary program, estimating the optimal body weight and screening for health problems associated with excessively low or high body fat.⁴ Furthermore, an optimal body composition is important for sports performance, with higher FM impeding sports performance⁵ and higher FFM being associated with increased strength.⁶

Body-composition changes following SCI include reduction in FFM and increase in whole body and regional FM.^{7–10} Although the positive effect of physical activity on FFM in the able-bodied population is well established, data from

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intervention studies on the effect of physical activity on body composition in the SCI population are somewhat unclear.^{11,12} Research from our laboratory has shown that habitual upper-body physical activity can decrease FM and increase regional FFM in the upper body.¹³

To our knowledge, no studies have compared estimates of body composition from field methods, SKF and BIA, using different prediction equations for both of these methods, to DXA in men and women athletes with SCI. These methods have been compared with DXA in sedentary individuals with SCI in only a couple of studies, results of which are conflicting.^{9,10,14} Clearly, more information is needed to determine the reliability and validity of these field methods and prediction equations, in the SCI population. In this context, the aim of this study was to compare %Fat estimates from SKF and BIA measurements using prediction equations with DXA estimates in athletes with SCI.

Methods

Participants

Sixteen highly active, Caucasian athletes with SCI (8 women, 8 men) were recruited from university varsity athletic teams. Physical activity level was determined using the Physical Activity Scale for Individuals with Physical Disabilities (PASIPD),¹⁵ which estimates a score based on the total weekly level of occupational, household and leisure-time physical activities. The SCI athletes were participating in varsity wheelchair basketball ($n=12$) and wheelchair racing programs ($n=4$) and had done so for the past 1–5 years, which involved 12 h of intense sport-specific and 3 h of resistance training per week (PASIPD score, mean $\pm$ s.d.: 31.8 ± 13.5). Injury levels ranged between T5 and L5 for SCI athletes, and 11 had complete SCI (8 women, 3 men), whereas five (all men) had incomplete SCI. None of the participants were able to ambulate. Information on American Spinal Injury Association (ASIA) classification for severity of injury of SCI athletes was not available. All subjects signed a consent form approved by the university's Institutional Review Board upon enrollment in the study.

Procedures

Participants were instructed not to consume alcohol nor exercise 16 h before testing sessions, with anthropometric measurements and body resistance from BIA measured in the morning after a 12-h fast. Participants were asked to empty their bladder before measurements were taken. All measurements were conducted by the same investigator. For females, testing was scheduled during days 7–14 from the start of their last menstrual period to control for water fluctuations due to sex-hormone status.

Anthropometry

Weight was measured to the nearest 0.1 kg on a beam scale (Magna-weigh, Howe Richardson, Ville St Pierre, Quebec, Canada) adapted for non-ambulatory individuals. Height was determined with all subjects in the supine position using a Gulick II retractable measuring tape (Country Technology Inc.,

Gay Mills, WI, USA) from the top of the head to the bottom of the heel. Individuals who could not extend all joints were segmented by joint and measured accordingly. BMI was computed as weight in kg divided by height in m² (kg/m²). Circumferences were measured to the nearest 0.1 cm at the umbilicus and hip (iliac crest), after subjects had exhaled to functional residual capacity. Circumference measurements were performed with the subject in a supine position due to postural differences in body morphology in SCI subjects.

Skinfold thickness

Skinfold thickness was measured using Harpenden calipers (John Bull, British Indicators Ltd., St Albans, UK) at nine sites on the right side of the body: triceps, subscapular, biceps, chest, midaxillary, paraumbilical, suprailiac, thigh and lateral calf. All measurements were taken consecutively, and then repeated a second time. A third measurement was taken if the first two measurements varied more than 0.5 mm. Established prediction equations based on Jackson and Pollock¹⁶ and Jackson, Pollock and Ward¹⁷ for men and women (JP₇; sites: chest, midaxillary, triceps, subscapular, abdomen, suprailiac, thigh), respectively, were used to estimate the body density. Three-site skinfold estimates that included only the upper body (JP_{3UB}; men: chest, triceps, subscapular; women: triceps, suprailiac, abdomen), and those that included the upper body and thigh (JP_{3TH}; men: chest, abdomen, thigh; women: triceps, suprailiac, thigh) were used for comparison purpose. Conversion of body density to %Fat was calculated using the Siri equation.¹⁸ In addition, %Fat was estimated using prediction equations developed by Evans *et al.*¹⁹ specifically for a non-disabled athletic population. We included a seven-site equation for athletes (EV₇; the same sites as JP₇) to match the JP₇ generalized equation and a three-site equation that included the abdomen, thigh and triceps (EV₃).

Bioelectrical impedance analysis

Bioelectrical impedance was measured using RJL Systems analyzer (Quantum X, Clinton Twp., MI, USA). The analyzer was calibrated before every measurement with a 500- Ω test resistor. Adhesive electrodes were placed on the participants' dorsal ankle and wrist after cleaning the skin with alcohol, with the participant lying supine for a minimum of 10 min. Body fat estimates were determined using the generalized equation of Stolarczyk *et al.*²⁰ (BIA_{GEN}), SCI-specific equation of Kocina and Heyward²¹ (BIA_{SCI}), and athlete-specific equation of Houtkooper *et al.*²² for women and that of Oppliger *et al.*²³ for men (BIA_{ATH}).

Dual-energy X-ray absorptiometry

Body composition was measured using dual-energy X-ray absorptiometry (DXA) (Hologic QDR 4500A, software version 11.1.3, Waltham, MA, USA). Participants wore lightweight clothing and removed all jewelry. All DXA scans were performed by an Illinois state licensed X-ray technologist and analyzed by the same investigator. The precision for DXA measurements of interest is between 1 and 1.5% in our laboratory. The legs of participants were strapped to the DXA

table to ensure there was no movement during the scan. No spasticity was observed during scans.

Statistical analyses

All data were analyzed with SPSS (Windows version 12.0, Chicago, IL, USA). Gender comparisons were made using independent-samples *t*-tests. Primary body composition outcomes of interest were assessed for normality using Shapiro–Wilk test statistics. Paired *t*-tests were performed to determine whether %Fat estimates were accurate in comparison to DXA. Bivariate correlations were used to assess the associations between body composition methods. To further characterize the degree of individual variability and impact of %Fat on measurement error (directional bias), a regression analysis was performed on Bland–Altman plots that were generated using the %Fat DXA and the difference or error scores (%Fat DXA–%Fat other estimate).²⁴ Standard error of the estimate (SEE) and total error (TE) were used to evaluate and classify the prediction error.²⁵ SEE represents the degree of deviation of individual scores from the regression line, thus indicating precision, and TE represents deviation from

the line of identity, and indicates accuracy. An α -level of 0.05 was considered significant.

Results

Descriptive characteristics are presented in Table 1. As expected, men were taller and weighed more than women. No gender difference was observed in BMI; however, again as expected, women had greater %Fat than men. All estimates of %Fat, shown in Table 2, calculated from equations using SKF consistently underestimated %Fat and were significantly different compared with DXA for both men (–6.9 to –12.3 %Fat) and women (–2.8 to –8.2 %Fat), except JP_{3UB}, which did not differ significantly from DXA in women ($P=0.42$; Figure 1). In contrast, BIA %Fat estimates did not significantly differ from DXA measures in women (–3.7 to 3.9 %Fat), and differed only when using the Oppliger athlete-specific equation in men (–7.0 $\pm$ 6.5 %Fat, $P=0.02$ vs –0.3 to –3.5%). On average, mean estimates of %Fat for the BIA equations were closer to DXA %Fat than SKF estimates for both men and women.

Table 1 Descriptive characteristics of athletes with spinal cord injury

	Women (n = 8)		Men (n = 8)	
	Mean $\pm$ s.d.	Range	Mean $\pm$ s.d.	Range
Age (years)	22.0 $\pm$ 2.7	18–27	21.9 $\pm$ 4.2	19–31
Time since injury (years)	16.9 $\pm$ 4.1	13–24	15.4 $\pm$ 7.3	4–25
Height (m)	1.53 $\pm$ 0.07 ^a	1.43–1.67	1.67 $\pm$ 0.12	1.42–1.80
Weight (kg)	48.7 $\pm$ 7.2 ^a	40.0–60.7	63.0 $\pm$ 10.9	43.0–74.8
BMI (kg m ^{–2})	20.8 $\pm$ 2.6	17.7–24.6	22.5 $\pm$ 2.1	19.4–25.5
Waist circumference, at umbilicus (cm)	67.8 $\pm$ 8.6	57.3–80.6	75.4 $\pm$ 9.6	62.0–87.2
Hip circumference (cm)	78.4 $\pm$ 7.4	68.0–87.0	79.1 $\pm$ 3.6	72.2–82.9
Waist-to-hip ratio	0.87 $\pm$ 0.08	0.74–0.96	0.95 $\pm$ 0.9	0.85–1.10

Abbreviation: BMI, body mass index.

^aSignificant gender difference, $P<0.05$.

Table 2 Correlations between DXA body fat percentage and body fat percentage assessed by SKF measurement equations and BIA

	Women (n = 8)					Men (n = 8)				
	%Fat (mean $\pm$ s.d.)	SEE	TE	Correlation coefficient	P-value*	%Fat (mean $\pm$ s.d.)	SEE	TE	Correlation coefficient	P-value*
DXA	31.9 $\pm$ 3.8					20.6 $\pm$ 8.4				
SKF										
JP ₇	24.0 $\pm$ 9.0	2.81	11.66	0.730	0.040	8.8 $\pm$ 10.5	3.30	14.37	0.931	0.001
JP _{3UB}	29.1 $\pm$ 11.1	3.18	12.12	0.635	0.091	9.7 $\pm$ 11.9	3.63	15.17	0.916	0.001
JP _{3TH}	24.5 $\pm$ 9.8	3.17	10.40	0.637	0.090	8.3 $\pm$ 8.7	4.86	13.96	0.842	0.009
EV ₇	23.7 $\pm$ 3.8	2.89	9.93	0.712	0.048	12.3 $\pm$ 5.5	2.95	10.45	0.945	0.000
EV ₃	26.3 $\pm$ 5.4	2.41	7.35	0.811	0.014	13.7 $\pm$ 7.1	2.34	8.41	0.966	0.000
BIA										
BIA _{GEN}	31.4 $\pm$ 5.6	3.39	5.06	0.568	0.141	24.1 $\pm$ 6.0	7.53	8.68	0.550	0.158
BIA _{SCI}	28.0 $\pm$ 7.1	3.60	8.12	0.484	0.224	20.9 $\pm$ 8.3	6.21	6.69	0.725	0.042
BIA _{ATH}	35.6 $\pm$ 9.0	3.46	9.31	0.542	0.165	13.6 $\pm$ 3.0	6.24	10.74	0.722	0.043

Abbreviations: BIA, bioelectrical impedance analysis; BIA_{ATH}, Houtkooper (female) and Oppliger (male) athlete-specific equations; BIA_{SCI}, Kocina and Heyward SCI-specific equation; DXA, dual X-ray absorptiometry; EV₃, Evans three-site equation, BIA_{GEN}, Stolarczyk generalized equation; EV₇, Evans's seven-site equation; JP_{3TH}, Jackson and Pollock's three-site equation with upper-body and thigh sites; JP_{3UB}, Jackson and Pollock three-site equation with upper-body sites; JP₇, Jackson and Pollock seven-site equation; SEE, standard error of the estimate; SKF, skinfold; TE, total error.

*P-value indicates significance of the correlation coefficient.

Figure 1 Mean differences between DXA estimates of %Fat and other prediction methods in (a) women and (b) men.

Correlations between DXA %Fat and %Fat from field body-composition methods are shown in Table 2. In women, the JP₇, EV₇ and EV₃ %Fat were the only equations significantly correlated to DXA %Fat, with the EV₃ having the highest correlation ($r=0.73$, 0.71 and 0.81 , respectively). All SKF estimates of %Fat were significantly correlated to DXA %Fat in men, with the EV₃ again having the strongest association ($r=0.97$). In contrast, none of the BIA equations were correlated with DXA %Fat in women. In men, both of the specific prediction equations, BIA_{SCI} and BIA_{ATH}, were associated with DXA %Fat ($r=0.73$ and 0.72 , respectively), whereas the BIA_{GEN} was not. To characterize the relation of estimates for the entire group, correlations for the whole group (men and women) were evaluated between the three best field method estimates of %Fat and DXA %Fat, representing a range of prediction equations: a generalized equation (JP₇), an athlete-specific equation (EV₃) and an SCI-specific equation (BIA_{SCI}) (Figure 2). To assess the precision of the BIA and SKF equations in predicting DXA %Fat, we calculated the standard error of the estimate (SEE) and for accuracy, TE for each field method (Table 2). Although most of the SEEs could be classified as good, TEs indicated that all estimates of %Fat were poor.²⁵

To assess the influence of %Fat on measurement error, Bland–Altman plots and linear regression analysis were used. Measurement error from the JP₇ was most strongly affected

Figure 2 Correlations between %Fat DXA and %Fat estimated by (a) Jackson and Pollock's seven-site (JP₇) ($r=0.90$, $P<0.001$); (b) Evans's three-site (EV₃) ($r=0.95$, $P<0.001$); and (c) BIA for SCI (BIA_{SCI}) ($r=0.73$, $P=0.001$).

($r=-0.45$, $P=0.08$; Figure 3a), whereas BIA_{SCI} was influenced in the opposite direction ($r=0.41$, $P=0.12$; Figure 3c). No directional bias in measurement error was seen in the EV₃ estimates ($r=0.04$, $P=0.88$; Figure 3b). Furthermore, the Bland–Altman plots show the large individual variability in measurement error for each %Fat estimate.

Discussion

To our knowledge, this is the first study to address the accuracy of %Fat estimations using SKF and BIA compared with DXA, in female and male athletes with SCI. Our findings indicate that neither field method accurately estimates %Fat using currently available prediction equations in this population because of systematic bias (based on TE classifications).²⁵ Skinfold thickness measurements systematically underestimated %Fat in this population, which is

Figure 3 Relation between %Fat DXA and measurement error in (a) Jackson and Pollock seven-site skinfold equation (JP_7) ($r=0.54$, $P=0.08$); (b) Evans three-site skinfold equation (EV_3) ($r=0.04$, $P=0.88$); and (c) Kocina and Heyward BIA equation for SCI (BIA_{SCI}) ($r=0.468$, $P=0.07$). Solid lines indicate mean error, dashed lines indicate ± 2 standard deviations and dotted line represents regression line.

consistent with previous studies in sedentary^{9,10} and athletic individuals with SCI.²⁶ BIA %Fat estimates varied greatly among prediction equations, possibly because of altered hydration status from training and altered extracellular fluid distribution due to SCI,^{7,27} or perhaps owing to inherent error in the prediction equation.

Skinfold %Fat underestimation in this study, especially in men, may result from a methodological problem related to

measurement of upper-body vs lower-body sites. Athletes, especially men, tend to have less upper-body FM; therefore, a skinfold prediction equation that includes mostly, or only, upper-body measurement sites would be expected to estimate a low %Fat for the whole body. This issue is further compounded with SCI athletes because it does not take into account the large amount of fat accumulation in the lower limbs, owing to disuse and muscle atrophy.⁸ However, estimates that included the thigh underestimated %Fat, as did the estimates relying on only upper-body measurement sites. In addition, prediction equations from SKF were developed and validated in non-disabled populations and include underlying assumptions about body fat distribution, which is altered in individuals with SCI compared with the non-disabled individuals^{8,13} and therefore may result in unreliable %Fat estimates. Also, many individuals with SCI have altered water distribution throughout the body,^{7,27} with some indication of edema in the lower limbs, which may change the relationship between skinfold thickness and subcutaneous fat, and therefore affect the predicted estimates.

To our knowledge, only one study has developed a skinfold prediction equation for individuals with SCI.²⁶ However, this study used underwater weighing as the reference method, which measures body density and therefore involves inherent error when used in the SCI population, owing to change in FFM density, specifically bone and potentially water, following SCI.^{7,26} Although the difference between DXA and all SKF %Fat estimates were quite large in our study, EV_3 appeared to be the most appropriate equation for our study population. Although this prediction equation underestimated %Fat by $\sim 6\%$, this underestimation was consistent across individuals. Furthermore, EV_3 estimates were highly correlated to %Fat DXA ($r=0.95$, $P<0.001$; $SEE=2.8$ %Fat), and this estimate was not influenced by variations in levels of %Fat (Figure 3b), whereas the other prediction equations showed bias with increasing DXA %Fat. The EV_3 may be more appropriate in part because it has been developed for an athletic population or, alternatively, because it incorporates the upper-, mid- and lower-body skinfold sites.

Taking into consideration some of the methodological problems inherent in SKF measurements that apply to the SCI population, BIA may be a more reliable field method as it measures resistance to electrical current through the whole body. Previous findings are conflicting, some suggesting that BIA can be accurate,¹⁰ whereas others show high variation when compared with a reference body composition assessment.¹⁴ Our findings showed that mean BIA %Fat estimates were closer to measured DXA %Fat than SKF estimates. However, the high variation in BIA estimates and poor correlations between BIA and DXA %Fat in this study indicate that BIA prediction equations are also a poor fit for this population, even under standardized conditions. Furthermore, the TE for BIA predictions of %Fat were poor, ranging from 5.06 to 10.74, suggesting a systematic bias.²⁵ The SCI-specific prediction equation also appeared to be inaccurate in both men and women, resulting in a weaker correlation and greater SEE in our sample ($SEE=6.19\%$ Fat)

than has been reported earlier in the SCI population ($R^2=0.87$, $SEE=3.2$ kg FFM).²¹ As the electrical current passes through extracellular water at low frequencies, such as 50 kHz used in the RJL bioimpedance analyzer in this study, differences in hydration status can greatly affect the measurements. In fact, generalized BIA equations are not recommended for use in athletes because of variability in hydration status due to training.²⁸ Using an athlete-specific BIA equation did not improve results compared with the SCI-specific equation in our study. As mentioned, water distribution is altered in individuals with SCI,⁷ with increased extracellular water,²⁷ further compounding the measurement error when using BIA in an athletic SCI population.

The main limitation of this study is the restricted sample size, which may have contributed to the high variation in %Fat estimates. Furthermore, we were not able to obtain participants' ASIA impairment classifications, limiting the description of the range of injury levels in this sample. All participants were college-aged athletes; therefore, our findings are not generalizable to all people with SCI. However, very little data exist on methodological body composition assessment comparisons in the athletic SCI population. The University of Illinois is renowned for its disability sports program, thus providing an athletic SCI population to study. Notably, this study reports the largest known sample of wheelchair athletes to compare field methods with DXA. Another potential limitation is the small but unknown error caused by spinal rods in this population (9 of 16 participants). Giangregorio and Webber²⁹ show that metal implants can indeed increase measured soft tissue. However, they also show that the percentage increase in both fat and lean soft tissue is within the range of measurement error ($\sim 0.7\%$). In addition, DXA was used in this study as a reference method, and although it is not an ideal standard, it has been shown to be an accurate method in the SCI population.⁸

In summary, prediction equations for SKF and BIA measurements do not accurately estimate %Fat when compared with DXA in men and women SCI athletes. Therefore, our results add to the literature and provide valuable information to clinicians working with athletes with SCI, wherein the body-composition assessment is a valuable tool in training programs. Further research, with larger samples, is needed to develop more appropriate prediction equations for body-composition assessment field methods in this population.

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