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A comparison of skinfolds and leg-to-leg bioelectrical impedance for the assessment of body composition in children

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Abstract

Background: This field-based investigation examined the congruence between skinfolds and bioelectrical impedance in assessing body composition in children.

Methods: Subjects were 162 female and 160 male children 10–15 years of age. Skinfold measures obtained at the triceps and medial calf and a leg-to-leg bioelectrical impedance system were used to determine percent fat using child-specific equations. Pearson product moment correlations were performed on the percent fat values obtained using skinfolds and bioelectric impedance for the entire data set. Separate correlations were also conducted on gender and age/gender subsets. Dependent t tests were used to compare the two techniques.

Results: Percent fat did not differ between skinfolds and bioelectrical impedance for the total subject pool. Bioelectrical impedance overestimated percent fat in girls by 2.6% and underestimated percent fat in boys by 1.7% ($p < 0.01$). Correlations between skinfolds and bioelectrical impedance ranged from $r = 0.51$ to $r = 0.90$.

Conclusions: Leg-to-leg bioelectrical impedance may be a viable alternative field assessment technique that is comparable to skinfolds. The small differences in percent fat between the two techniques may have limited practical significance in school-based health-fitness settings.

Background

The prevalence of obesity in the United States has grown dramatically in recent years [1,2]. In fact, epidemiological studies have shown that presently there are more overweight adult Americans than individuals of normal weight. In addition, the incidence of childhood obesity has increased by 25% over the past 20 years [2]. Although the causes of obesity are somewhat controversial the health risks associated with obesity are well documented. As such an accurate assessment of body composition has

important clinical and health-fitness implications. The "gold standard" for body composition assessment has traditionally been underwater weighing [3]. This measurement technique typically requires multiple trials, complete body immersion and the measurement of residual lung volume. This approach in assessing body composition is time consuming, requires fairly sophisticated instrumentation is difficult to administer and is contraindicated or impractical in certain clinical subgroups, such as the elderly, individuals with cardiopulmonary disease

or hypertension, subjects who are uncomfortable being immersed in water and children.

Therefore, alternate methods of body composition assessment that are easier and safer to administer have been developed. One such technique involves the use of skinfold calipers to measure subcutaneous fat at various anatomic sites. Although widely used in laboratory and field settings, the accuracy of this procedure is predicated upon the technical experience and training of the investigator. Inter- and intra-individual variability associated with the selection of skinfold sites, the size/depth of the skinfold measurement and the time delay in reading the calipers have all been shown to markedly reduce the accuracy of this procedure [4]. In the hands of highly trained and experienced individuals the error associated with the use of skinfolds to predict body fatness is less than 3% [4]. However, interindividual variability remains a major source of error associated with this technique. Clearly the accurate assessment of body composition using skinfold calipers requires specially trained and experienced personnel [4]. This has somewhat limited the widespread application of skinfold assessment as a field-based tool and has led to the development of alternative techniques for the determination of body composition. One such technique is bioelectrical impedance analysis (BIA). This procedure takes very little time, is easy to administer, requires no specialized training or practice for the investigator and is non-invasive. Bioelectrical impedance analysis typically involves placing electrodes on the ear and toe of a subject who is resting in a supine position. An alternating, sub-

threshold current (less than 1 mA) is then transmitted through the body. The basic premise of this technique is that lean tissue acts as an electrical conductor while fat resists the transmission of the electrical impulse. Equations that utilize electrical impedance to estimate percent fat have been developed for athletes, adults and children [5,6].

A recently developed BIA system obviates the need to employ cutaneous electrodes [7–10]. This technology employs a "leg-to-leg" electrode system requiring approximately 8 seconds to administer. No special skill or training is necessary to administer the assessment and it is non-threatening. This makes it especially useful in assessing body composition in a pediatric population. As such this technology could become part of regular school-based physical examinations, used to track changes in body composition related to growth and development or to assess the efficacy of interventions designed to reduce body fat. However, previous research has shown that bioelectrical impedance derived body composition may be affected by hydration status, ambient temperature and recent exercise [11,12]. Unfortunately, tight control over these potentially confounding variables may not be possible in field-based or school environments. Therefore, this investigation was undertaken to examine the congruence between skinfolds and a leg-to-leg BIA system in assessing body composition in a cohort of adolescent male and female students. This study was conducted in a non-laboratory setting and no attempt was made to control subject activity prior to the assessment of body composition.

Table 1: Subject Characteristics

		Height (cm)	Weight (kg)	BMI (kg/m ²)	SF-Fat (%)	BIA-Fat (%)
All	M	157.0	57.1	22.7	27.0	27.5
	SD	11.0	18.3	5.7	13.0	11.8
Male	M	158.0	53.8	21.2	22.6	20.9*
	SD	12.7	13.9	3.8	12.0	8.6
Female	M	156.1	60.4	24.2	31.5	34.1*
	SD	8.9	21.3	6.8	12.4	10.9
Male (10–11 yr)	M	146.4	45.5	20.8	26.0	24.6*
	SD	7.5	12.9	4.6	13.1	10.3
Male (12–13 yr)	M	159.0	55.3	21.6	20.6	23.9*
	SD	9.5	15.1	4.4	7.3	13.7
Male (14–15 yr)	M	168.3	60.6	21.3	17.9	17.7
	SD	8.5	9.4	2.3	7.4	5.8
Female (10–11 yr)	M	150.0	48.0	21.1	27.5	29.9*
	SD	8.0	13.8	4.9	11.4	8.9
Female (12–13 yr)	M	157.3	64.5	25.9	33.5	36.8*
	SD	6.9	19.5	6.9	12.8	11.3
Female (14–15 yr)	M	161.5	69.9	26.1	33.9	36.4*
	SD	7.7	23.4	7.5	12.1	11.2

Values are means ± standard deviations; * p < 0.01 Indicates means are significantly different between SF-Fat and BIA-Fat; BMI = body mass index; SF-Fat = percent body fat determined using skinfolds; BIA-Fat = percent body fat determined using leg-to-leg Bioelectrical Impedance Analysis

Methods

Subjects

Body composition measures were obtained as part of health fitness assessments conducted at local high schools and in conjunction with physical examinations conducted prior to participation in summer camps administered by the Department of Health, Physical Education and Recreation at the University of Pittsburgh. Subjects were healthy, clinically normal volunteers who were recruited with parental consent. Age and gender were recorded prior to the assessment of body composition. A total of 322 children participated in this investigation. Subject demographic data are presented in Table 1.

Protocol

Skinfold measurements

Lange skinfold calipers were used to assess tricep (vertical fatfold taken midway between the olecranon process and acromion process on the posterior aspect of the arm) and calf (vertical skinfold taken on the medial aspect of the calf at the point of largest circumference) skinfold thickness [6]. All measurements were taken on the right side of the body. The average of three measures was calculated for each site and the following equations were used to predict percent fat [6]:

Females: %fat = 0.610 (sum of average skinfolds) + 5.0

Males: %fat = 0.735 (sum of average skinfolds) + 1.0

All skinfold measurements were taken by a team of specially trained technicians (n = 4) with a minimum of three years experience in the use of skinfold calipers to determine body composition. Each subject was assessed once.

Leg-to-Leg Bioelectrical Impedance

Prior to the leg-to-leg BIA assessment of body composition subjects removed their shoes and socks. Height was assessed using a Detecto physician's scale. Subject height in cm was then entered into the BIA system (Tanita Model #TBF-305) and the appropriate gender option selected. The child mode was used for all assessments. The subject wearing a tee shirt and shorts was instructed to stand with his/her legs straight, feet parallel with the heel and fore-foot placed on the metal plates of the leg-to-leg BIA system. A sub threshold electrical current was then transmitted through the body from leg to leg and an impedance based percent fat value was determined. The equations used to predict percent fat from impedance are proprietary.

Data Analyses

Pearson product moment correlations were performed on the body composition (i.e. %fat) values obtained using skinfold calipers and leg-to-leg BIA for the entire data set

(n = 322). In addition separate correlations were performed for the male (n = 160) and female (n = 162) data sets. The data were further subdivided by age and gender. Correlational analysis was also performed on these subgroups. In order to explore any systematic differences between the two body composition assessment techniques the difference in fat free tissue between leg-to-leg bioelectrical impedance and skinfold calipers was plotted against the average fat-free mass [13]. Dependent t tests were used to compare body composition values obtained using skinfold calipers and leg-to-leg BIA. Separate analysis was conducted on the entire subject pool as well as gender and gender/age subsets. In addition, the difference in percent fat determined by bioelectrical impedance and skinfolds was plotted against the average percent fat obtained from the two body composition techniques. This Bland-Altman distribution is presented in Figure 1.

Results

Subject characteristics and a comparison of percent fat values obtained via leg-to-leg BIA and skinfolds are presented in Table 1. This information is presented for the entire subject pool (n = 322) and separately as a function of gender and gender/age (i.e. 10–11, 12–13 and 14–15 yr). Percent fat values did not differ between techniques for the total subject cohort. However, the leg-to-leg BIA system overestimated the percent fat in girls by 2.6% (p < 0.01). When the data for the female subjects were examined as a function of the 3 age subgroups the leg-to-leg BIA resulted in an overestimation (p < 0.01) of the percent fat by 2.4 to 3.3% (Table 1). A comparatively smaller disparity (1.7%) was noted between techniques for the male subjects. The leg-to-leg BIA underestimated the skinfold percent fat by 1.4% in boys 10–11 yr and overestimated skinfold percent fat by 3.3% in boys 12–13 yr. No difference in body composition was noted between the two techniques in the oldest group of boys.

The results of the correlational analysis of percent fat obtained using skinfolds and leg-to-leg BIA are presented in Table 2. Significant (p < 0.01) correlations ranged from r = 0.51 to r = 0.90. The standard error of estimate ranged from 3.9 to 7.0%.

In Figure 1 the difference in percent fat obtained via skinfolds and leg-to-leg bioelectrical impedance is plotted versus the mean percent fat determined by the two techniques. The solid line represents the mean difference between the two techniques and the dashed lines correspond to one standard deviation. This Bland-Altman distribution does not indicate a systematic difference between the percent fat measured using leg-to-leg BIA and skinfolds.

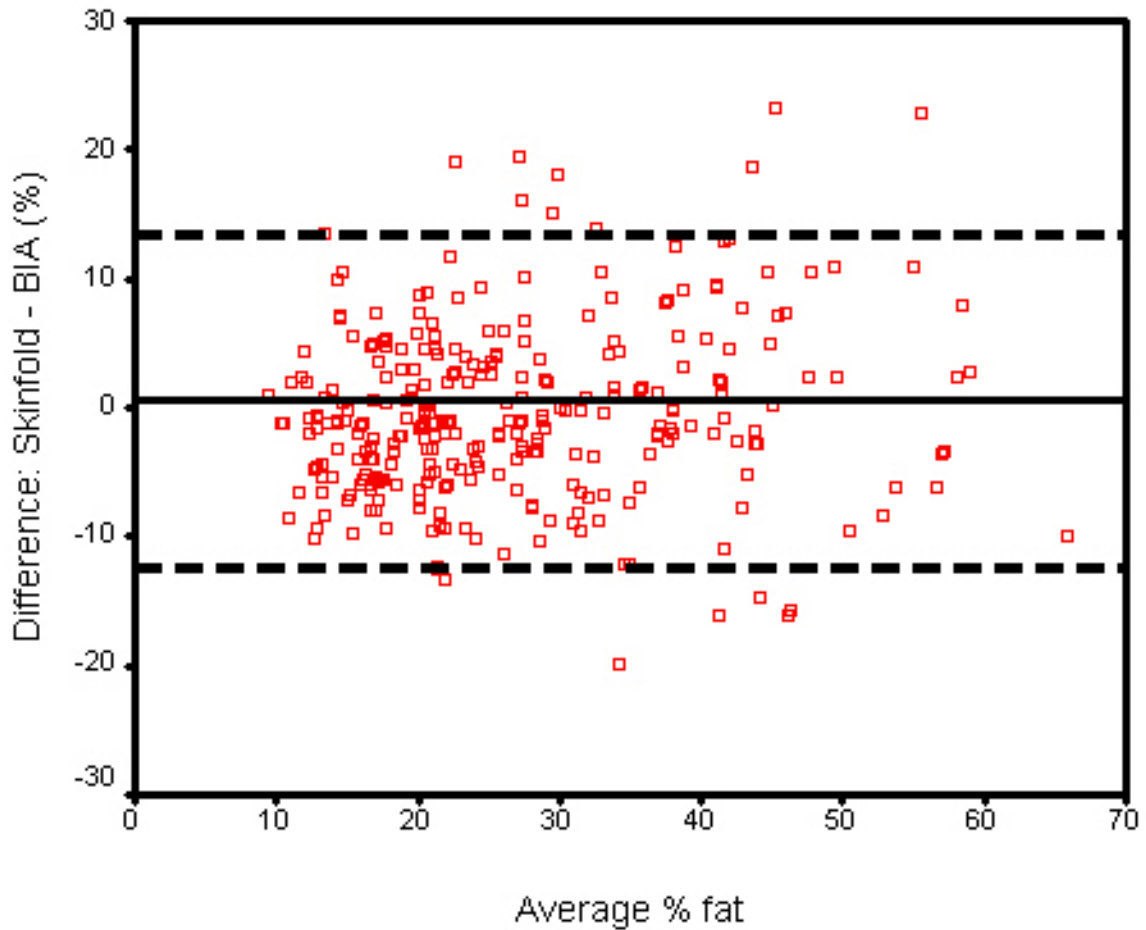


Figure 1

The difference in percent fat determined by bioelectrical impedance and skinfolds versus the average percent fat. The solid line represents the mean difference between the two techniques and the dashed lines correspond to one standard deviation.

Table 2: Intermethod correlations for percent fat

Subjects	N	r*	r ²	SEE
Total	322	0.85	0.72	6.2
Male	160	0.83	0.69	4.8
Female	162	0.86	0.74	5.5
Male (10–11 yr)	58	0.90	0.81	4.5
Male (12–13 yr)	42	0.86	0.74	7.0
Male (14–15 yr)	61	0.51	0.26	5.0
Female (10–11 yr)	58	0.90	0.81	3.9
Female (12–13 yr)	50	0.83	0.69	6.3
Female (14–15 yr)	52	0.83	0.69	6.2

*All correlations are significant $p < 0.01$; SEE = standard error of estimate

Discussion

The most commonly used system to assess body composition in field-based settings such as physical education classes is a skinfold technique in which double thickness subcutaneous fat is measured at discrete anatomical sites [6]. However, this technique has error introduced by inter- and intra-measurement variability may limit the widespread utility of this technique in health-fitness settings. An alternate field-based technique to assess body composition that eliminates the need to use specially trained and experienced technicians is leg-to-leg BIA. Several factors such as hydration status and previous exercise have been shown to negatively impact the BIA assessment of body composition [11,12]. However, there is a lack of consensus regarding the extent to which these factors may confound the BIA assessment of body composition. However, the systematic and uniform control of test conditions when assessing a large number of young children and adolescents in a school setting is difficult to attain. Therefore, this field-based investigation was undertaken to examine the congruence between skinfolds and BIA in assessing body composition in male and female adolescents. Such information is important in establishing the practicality of a leg-to-leg BIA instrument in determining body composition in a mixed gender pediatric cohort.

The Bland-Altman plot (Figure 1) indicates that a systematic difference in percent fat values was not apparent between skinfolds and leg-to-leg BIA techniques. This observation is similar to that shown previously when whole body BIA was compared to underwater densitometry. Houtkooper et al. [14] in a seminal study compared whole body BIA, underwater densitometry and anthropometric measures in a group of 10–14 year old children. Subjects were required to abstain from vigorous physical activity in the 12 hours preceding assessments and subjects were tested three hours post-absorptive. A standard error of 4.2% was reported when using whole body BIA to predict percent body fat in this population sub-set. The absence of tightly controlled pre-test behaviors in the present investigation coupled with a different BIA technology and comparison measure of body composition may have contributed to the comparatively greater SEE noted presently.

Lukaski et al [15] reported that the failure to control pre-test behaviors related to physical activity and fluid consumption in intercollegiate athletes resulted in a significant discrepancy from the criteria condition in which these parameters were tightly controlled. Body weight was on average 2.3 kg lower in the uncontrolled trials. This difference may have been the result of hypohydration secondary to intense intercollegiate practices or exercise and inadequate fluid intake. In contrast Liang and Norris [16] reported that a 1 kg acute loss in body weight following

treadmill running/walking had no effect on the BIA determination of percent body fat. Therefore, a dose response relationship may exist between fluid loss and body composition measured using BIA. The question of whether hypohydration effects the BIA assessment of body composition in children remains to be answered.

With respect to the impact of previous exercise on the BIA measurement of body composition, Lukaski et al. reported a significant alteration in BIA determined percent fat consequent to exercise. In contrast, Liang and Norris [16] reported that treadmill walking or running at speeds ranging from 147–188 m · min⁻¹ and 2.5% grade had no effect on the BIA determination of percent fat. More recently, Goss et al. [17] reported that following a standard progressive cycle ergometer exercise test administered to establish VO₂ peak, percent fat measured using BIA decreased by 0.4 and 1.2% in male and female children 10–12 years of age, respectively. These changes in percent fat are similar to that attributable to the day-to-day variability in BIA measures [10]. A modest amount of exercise does not seem to effect BIA measurements obtained on children. However, the volume and/or intensity of exercise that introduces a change in BIA percent fat that has a practical significance is unknown.

Utter et al. [9] also examined the congruence between body composition obtained via skinfolds and leg-to-leg BIA. Subjects in this investigation were intercollegiate wrestlers. Data collection was conducted during the pre-season, early in the competitive season and in conjunction with several tournaments. Given the almost universal approach among intercollegiate wrestlers to utilize exercise and dehydration to achieve weight loss there was no control over physical activity and hydration status preceding the measurement period. In this context, the field conditions and inherent limitations in the Utter et al. [9] study were similar to those noted presently. However, in the Utter et al. [9] study the wrestlers were male, comparatively lean (average % fat ranged from 10.1 to 11.1%) and fairly homogeneous with respect to % body fat (standard errors ranged from 0.2 to 0.4%). Nonetheless, generally similar correlations were observed in the Utter et al. [9] ($r = 0.67-0.83$) and current ($r = 0.51-0.90$) investigation.

The standard errors of estimate reported by Utter et al. [9] are somewhat lower (2.2–3.5%) than those observed presently (3.9–7.0%). The comparatively larger SEE in the current investigation may be related to the wide range of body fatness and the use of a mixed gender cohort. In all cases the "child" mode of the BIA unit was employed. However, Tanner stages of maturation were not obtained. As such, variability in the leg-to-leg BIA measures of percent fat may also have been influenced by the biological

maturity of the subjects. This potential lack of homogeneity with respect to maturity and total body water may, in part, explain the weaker correlation ($r = 0.51$) noted in the older (i.e. 14–15 yr) male subjects. Therefore, the use of a universal "child" BIA equation may not be appropriate especially for older male adolescents. Nunez et al. [10] reported a strong correlation coefficient ($r = 0.89$) between leg to leg BIA and DEXA in adult male (33.1 ± 9.5 yr) and female (33.9 ± 11.0 yr) subjects. In this population variability in maturity would not influence the BIA measure of body composition.

Conclusions

In summary, the results of this field-based investigation indicate that bioelectrical impedance analysis and skinfold caliper techniques result in statistically different ($p < 0.01$) percent fat values in adolescent boys and girls. Bioelectrical impedance analysis overestimated percent fat in the female cohort by 2.6% and underestimated percent fat by 1.7% in the male subjects. In addition, there were outliers in which the difference between the two techniques was somewhat greater than the mean difference (Figure 1). Therefore, when characterizing individual risk associated with body composition or when prescribing diet/exercise interventions it is important to recognize the potential differences between BIA and skinfolds. However, the comparatively small mean difference in percent fat between the two techniques may have limited practical significance especially in settings where individuals trained in the use of skinfolds are not available. The leg-to-leg BIA appears to be a viable alternative field assessment system that results in percent fat values that are comparable to those obtained using skinfold measurements. In addition, BIA eliminates the inter and intra-individual measurement variability that is inherent with skinfolds. This BIA technique is easy to administer, takes less time than skinfolds, is portable and non-threatening, making it a good choice when assessing adolescents. Stringent pre-test guidelines with respect to subject behavior (i.e. hydration status, previous exercise) may be necessary when making within children comparisons over time. Future studies should examine the accuracy of the leg-to-leg BIA system in younger children (less than 10 years old) and adolescents older than 15 yr. In addition, the efficacy of this leg-to-leg BIA system in assessing changes in body composition secondary to maturation and/or nutrition and exercise interventions should be investigated.

Author's Contributions

F. G. participated in study design, supervised activities of the research team and drafted the manuscript.

R R. participated in study design and coordination and manuscript editing.

A. W. and K. A. participated in study coordination and data analysis.

K. S., M. L., J. T. and C. D. participated in data collection, data analysis and study coordination.

All authors approved the final manuscript.

References

1. Flegal KM, Carroll MD, Kuczmarski RJ and Johnson CL: **Overweight and obesity in the United States: prevalence and trends, 1960–1994.** *Int J Obes* 1998, **22**:39-47.
2. Flegal KM: **The obesity epidemic in children and adults: current evidence and research issues.** *Med Sci Sports Exerc* 1999, **31(11)**:s509-s514.
3. Wilmore JH and Costill DL: **Physiology of Sport and Exercise.** Champaign, IL: Human Kinetics 1999.
4. Pollock ML and Jackson AS: **Research progress in validation of clinical methods of assessing body composition.** *Med Sci Sports Exerc* 1984, **16**:606-613.
5. Bioelectrical impedance analysis in body composition measurements: **National Institutes of Health Technology Assessment Conference.** *Am J Clin Nutr* 1996, **64(Suppl)**:524s-532s.
6. Roche A, Heymsfield SB, Lohman TE and eds: **Body Composition.** Champaign, IL: Human Kinetics 1996.
7. Cable A, Nieman DC, Austin M, Hozen E and Utter AC: **Validity of the leg-to-leg bioelectrical impedance measurements in males.** *J Sports Med Phys Fitness* .
8. Utter AC, Nieman DC, Ward AN and Butterworth DE: **Use of the leg-to-leg bioelectrical impedance method in assessing body composition change in obese women.** *Am J Clin Nutr* 1999, **69**:603-607.
9. Utter AC, Scott JR, Oppliger RA, Visich PS, Goss FL, Marks BL, Nieman DC and Smith BW: **A comparison of leg-to-leg bioelectrical impedance and skinfolds in assessing body fat in collegiate wrestlers.** *J Strength Con Res* 2001, **15(2)**:157-160.
10. Nunez C, Gallagher M, Visser M, Pi-Sunyer FX, Wang Z and Heymsfield SB: **Bioimpedance analysis: Evaluation of leg-to-leg system based on pressure contact foot-pad electrodes.** *Med Sci Sports Exerc* 1997, **29**:524-531.
11. Canton JR, Mole PA, Adams WC and Heustis DS: **Body composition analysis by bioelectrical impedance analysis: effect of skin temperature.** *Med Sci Sports Exerc* 1988, **20**:489-491.
12. Deurenburg P, Weststrate JA, Paymans I and Van Der Kooy K: **Factors affecting bioelectrical impedance measurements in humans.** *Eur J Clin Nutr* 1988, **42**:1017-1022.
13. Altman DG and Bland JM: **Measurement in medicine: The analysis of method comparison studies.** *Statistician* 1983, **32**:307-317.
14. Houtkooper LB, Lohman TG, Going SB and Hall MC: **Validity of bioelectrical impedance for body composition assessment in children.** *J Appl Physiol* 1989, **66(2)**:814-821.
15. Lukaski HC, Bolonchuk WW, Siders WA and Hall CB: **Body composition assessment of athletes using bioelectrical impedance measurements.** *J Sports Med Phys Fitness* 1990, **30**:434-440.
16. Liang MTC and Norris S: **Effects of skin blood flow and temperature on bioelectrical impedance after exercise.** *Med Sci Sports Exerc* 1993, **25(s)**:1231-1239.
17. Goss FL, Robertson RJ, Dube J, Rutkowski J, Andreacci J, Lenz B, Ranalli J and Frazee K: **Does exercise testing affect the bioelectrical impedance assessment of body composition in children?** *Ped Ex Sci* 2003, **15**:216-222.