Original articles

Comparison of different techniques to measure body composition in moderately active adolescents

Antonino De Lorenzo, Iacopo Bertini, Nicola Candeloro, Leonardo Iacopino, Angela Andreoli, Marta D Van Loan

Abstract

***Objective*—To evaluate the differences in the estimate of body fat percentage (%FM) and the amount (kg) of fat free mass (FFM) by different methods in 26 moderately active adolescents very similar in age, body fatness, and training status.**

***Methods*—Mean (SD) age was 16.7 (0.9) years, height was 177.0 (5.1) cm, and weight 68.0 (5.2) kg. %FM was assessed using dual-energy *x* ray absorptiometry (DXA) and two skinfold prediction equations: that of Slaughter *et al* (%FM Sla) and that of Deurenberg *et al* (%FM Deu). In the same way, FFM was measured using DXA and different impedance equations: those of Suprasongsin *et al* (FFM Sup), Schaefer *et al* (FFM Sch), Houtkooper *et al* (FFM Hou), and Deurenberg *et al* (FFM Deu). To determine the interchangeability of the different methods of measuring %FM and FFM, one way analysis of variance, standard error (SE), and coefficient of variation (CV%) ((SD/mean) × 100) were used.**

***Results*—On average, no significant statistical differences were observed between the values determined for %FM: DXA value, 11.7 (5.4)%; %FM Sla, 10.9 (4.0)%; %FM Deu, 11.5 (2.3)%. On the other hand, SE and CV% between each pair of the three methods used showed very large variability. With regard to the measurement or prediction of FFM, the mean value measured by DXA was significantly higher than that predicted by the equation of Sch (+7.2 kg, p<0.001), Deu (+3.2 kg, p<0.001), and Hou (+2.6 kg, p<0.001), whereas it was lower than that predicted by the equation of Sup (−1.6 kg, p<0.05). The Hou and Deu values were the only two that, on average, did not differ in a statistically significant way, although they showed the highest CV%.**

***Conclusions*—In our sample of moderately active adolescents the estimated values for %FM and FFM appear to be highly dependent on method.**

(*Br J Sports Med* 1998;**32**:215–219)

Keywords: body composition; dual-energy *x* ray absorptiometry; skinfold equations; impedance equations; adolescents

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Accepted for publication
26 February 1998

In studies of body composition, body weight is usually divided into two chemically based components, fat free mass (FFM), which includes water, protein, and mineral, and fat mass (FM).[1] Determination of FM and FFM in growing subjects is a complex problem, because the chemical composition of FFM changes with growth.[2 3] Accurate measurements of the body composition in young boys are essential to evaluate nutritional status and health implications.

Skinfold thickness measurement and bioelectrical impedance analysis (BIA) are two widely used indirect techniques for the assessment of body composition because they are easy to use and are not invasive.[4 5] Many skinfold and impedance equations have been developed to predict FM and FFM from simple anthropometric and bioelectric parameters. Unfortunately, changes in body shape, fat proportion, fat patterning, and water and mineral content of FFM may invalidate the assumptions underlying these techniques.[4–8] Furthermore, different reference methods have been used to develop these equations.[7 9–13]

In recent years, dual energy *x* ray absorptiometry (DXA) has been introduced to evaluate body composition in young subjects.[14] It can be used to estimate bone mineral density and bone mineral content (BMC) and it may be useful for estimating soft tissue composition: FM and soft fat free tissue (SFFT = FFM − BMC). SFFT and BMC can then be combined to represent FFM.

In general, previously published studies have reported data obtained using different methods in very heterogeneous groups of non-active children and adolescents.[15–17] There is little information about groups of more homogeneous adolescents and body composition measurements obtained using different techniques.

For this reason, the purpose of our study was to evaluate the interchangeability of the DXA method, skinfold thickness measurement technique, and BIA in the determination of percentage of FM and amount of FFM in a very homogeneous group of male soccer players.

Methods

The 26 male subjects were healthy adolescents, between 15.5 and 18.0 years of age, who participated in a regional soccer championship.

All the subjects exercised regularly for 90–120 minutes a day on four days a week. All boys and their parents provided written consent for participation in the study and the procedures were approved by the University of Tor Vergata Human Experimentation Ethics Committee.

The following measurements were taken by one doctor according to conventional criteria and measuring procedures[18]: body weight and body height were measured to the nearest 100 g and 0.5 cm respectively; body mass index (BMI) was calculated using the formula weight (kg)/height^2 (m^2). Four skinfolds were measured: triceps, biceps, subscapular, suprailiac. The measurements were made in triplicate on the left side of the body, and the mean of the three values was calculated for subsequent analysis. To measure skinfold thickness, a Holtain caliper (Holtain Ltd, Crymych, UK) was used.

To estimate body fat percentage (%FM) from anthropometric measurements, the equations of Slaughter *et al*[9] (Sla) (based on a multicomponent method of body composition as reference method) and Deurenberg *et al*[10] (Deu) (underwater weighing) were used.

The basic theory of bioimpedance has been presented elsewhere.[19] BIA measurements were performed with the subject in a supine position, as described by Lukaski *et al*,[19] at the left side of the body, using an impedance analyser (model BIA RJL Systems 101 S; Akern, Florence, Italy) that utilises a 50 kHz alternating current. The left side of the body was chosen for both skinfold and BIA measurements because, like other authors,[10] we generally take measurements on the non-dominant side. We believe that, in normal subjects, differences between measurements taken on the left and right are generally small. To calculate the amount of FFM, we chose the equations of Houtkooper *et al*[12] (Hou) (multicomponent model), Deurenberg *et al*[7] (Deu) (underwater weighing), Schaefer *et al*[11] (Sch) (total body potassium) and Suprasongsin *et al*[13] (Sup) (dilution technique).

FM, SFFT, and BMC were measured with a DXA total body scanner (model DPX, software version 3.6; Lunar, Madison, Wisconsin, USA) that used a constant potential *x* ray source at 12.5 fJ and a K-edge filter to achieve a congruent beam of stable dual energy content (40 and 70 keV). FM was calculated from the soft tissue attenuation ratio, which was defined as the ratio of beam attenuation at the lower energy relative to that at the higher energy. %FM and FFM (kg) were calculated as: %FM = (FM/(FM + SFFT + BMC)) × 100; FFM (kg) = (SFFT + BMC) (kg). The reproducibility of our DXA instrument for the different body composition measurements has been reported previously.[20]

The data were analysed using SPSS 6.0 for Windows statistical software (SPSS Inc., Chicago, Illinois, USA). Values are expressed as mean (SD). The %FM values obtained by DXA and skinfold measurement were compared using one way analysis of variance, with post hoc Bonferroni test when values were significantly different. The same test was used to compare FFM values measured by DXA and BIA. The significance level was set at $p<0.05$. Mean (SD) and coefficient of variation of the differences (CV% = 100 × (SD/mean)) were calculated for each pair of methods used. Methodological differences in estimates of %FM and FFM between the various methods were also analysed by the method of Bland & Altman.[21] The appropriate value of *t* was taken from statistical tables.

Table 1 Physical characteristics of the subjects. Values are mean (SD)

Characteristic	*Value*
n	26
Age (years)	16.7 (0.9)
Weight (kg)	68.0 (5.2)
Height (cm)	177.0 (5.1)
BMI (kg/m^2)	21.7 (1.7)
Skinfolds (mm) (left side)	
Biceps	4.5 (1.2)
Triceps	6.8 (2.0)
Subscapular	8.4 (2.5)
Suprailiac	8.5 (4.4)
BIA (ohms)	
Resistance	495 (40)
Reactance	60 (8)
DXA (kg)	
FM	8.1 (4.2)
SFFT	56.5 (4.1)
BMC	3.2 (0.3)
Weight	67.8 (5.2)

BMI, body mass index; BIA, bioelectrical impedance analysis; DXA, dual energy *x* ray absorptiometry; FM, fat mass; SFFT, soft fat free mass; BMC, bone mineral content.

Table 2 Body fat percentage values measured by dual energy x ray absorptiometry (DXA) and calculated by the equations of Slaughter et al[9] and Deurenberg et al[10]

	Slaughter	*Deurenberg*
DXA (11.7 (5.4))	0.8 (3.1) (387%)	0.2 (3.4) (1700%)
Slaughter (10.9 (4.0))		−0.6 (2.0) (317%)
Deurenberg (11.5 (2.3))		—

Values are mean (SD) difference (with the coefficient of variation in the second set of parentheses) between the column method and the row method.

Table 3 Bland-Altman comparison among each pair of all three of the methods used to estimate body fat percentage: dual energy x ray absorptiometry (DXA), equations of Slaughter et al[9] and Deurenberg et al[10]

	Slaughter	*Deurenberg*
DXA	−7.7, 9.3	−9.1, 9.6
Slaughter		−4.8, 6.0
Deurenberg		—

Values are 95% limits of agreement. Differences are calculated as the column method minus the row method.

Results

Table 1 shows physical characteristics of the subjects. According to the average value of BMI, our sample of teenagers was in the healthy range.

Table 1 also gives descriptive analyses of anthropometric, BIA, and DXA measurements of the subjects. The sample was characterised by a relatively low percentage of body fat. No significant difference in %FM was observed between the DXA values and those calculated with the Sla and Deu formulas (table 2). The DXA value, on average, was very similar to that obtained with the Sla (+ 0.8%) and Deu (+

Table 4 Fat free mass (kg) values measured by dual energy x ray absorptiometry (DXA) and calculated by the equations of Suprasongsin et al[13] (Sup), Schaefer et al[11] (Sch), Houtkooper et al[12] (Hou), and Deurenberg et al[7] (Deu)

	Sup	*Sch*	*Hou*	*Deu*
DXA (59.7 (4.4))	−1.6 (2.5)* (156%)	7.2 (2.8)** (39%)	2.6 (2.5)** (96%)	3.2 (2.2)** (67%)
Sup (61.3 (4.2))		8.8 (2.0)** (23%)	4.1 (0.8)** (19%)	4.8 (1.9)** (40%)
Sch (52.5 (3.8)			−4.6 (1.3)** (28%)	−4.0 (2.4)** (60%)
Hou (57.1 (4.1))				−0.7 (2.0) (333%)
Deu (56.5 (3.9))				—

Values are mean (SD) difference (with the coefficient of variation in the second set of parentheses) between the column method and the row method.
*p<0.05; **p<0.001 (Bonferroni test).

Table 5 Bland-Altman comparison among each pair of all three of the methods used to estimate fat free mass (kg): dual energy x ray absorptiometry (DXA), equations of Suprasongsin et al[13] (Sup), Schaefer et al[11] (Sch), Houtkooper et al[12] (Hou), and Deurenberg et al[7] (Deu)

	Sup	*Sch*	*Hou*	*Deu*
DXA	−8.3, 5.3	−0.5, 14.9	−4.2, 9.4	−2.9, 9.4
Sup		3.1, 14.3	1.9, 6.3	−0.6, 10.2
Sch			−8.2, −1.0	−10.4, 2.6
Hou				−4.9, 6.3
Deu				—

Values are 95% limits of agreement. Differences are calculated as the column method minus the row method.

0.2%) formulas. The mean (SD) and the CV% of the differences among each pair of all three of the methods used showed a high variability in the %FM values obtained from the different techniques (table 2). The results of the Bland-Altman analysis confirmed that the 95% limits of agreement between all methods were wide (table 3).

With regard to the measurement or prediction of FFM, no significant differences were observed between FFM predicted by the Hou and Deu equations (mean difference = 0.6 kg) (table 4). In particular, the Sch equation underestimated FFM compared with both the DXA value (−7.2 kg) and the other impedance equations (Sup −8.8 kg, Hou −4.6 kg, and Deu −4.0 kg). DXA overestimated the FFM value compared with that predicted by the Deu (+3.2 kg) and Hou (+2.6 kg) equations, whereas it underestimated FFM when compared with that predicted by the Sup formula (−1.6 kg) (table 4). For FFM measurement also, there was large variability among the different methods, as shown by the mean difference (SD) and CV% values (table 4). Table 5 gives the results of the Bland-Altman analysis for FFM estimates. Comparison of the various methods with DXA showed wide differences in FFM estimates, in particular for those obtained with the Sch equation.

Discussion

In body composition studies, body mass is classically divided into two components: FM and FFM. For practical purposes, FM and FFM are often evaluated utilising skinfold measurement and BIA, applying specific regression equations for age and sex. These equations, however, are developed with statistical regression techniques, using, as reference methods, different techniques—for example, densitometry, ^{40}K counting, dilution methods. These techniques have a different precision and degree of accuracy with regard to FM and FFM measurement.[22 23] These assumptions underlying the reference methods used for the calculation of body composition in adults cannot be applied to growing children.[3] In the absence of cadaver analysis as the "gold standard", no single technique can be accepted as the most appropriate reference method. Thus, it is typical in body composition studies to determine the differences in FM and FFM estimates by applying different methods.

DXA is available in many body composition laboratories and it can be readily used for measurement of body composition in children and adolescents.[24] There is some controversy about whether DXA should be considered a "gold standard" method for body soft tissue measurement. Errors in FM(%) estimates can result from inaccurate detection of FM in the trunk region,[25] variation in tissue thickness,[26] and variation in water content of FFM, although the hydration status seems to have a relatively small effect on the evaluation of soft tissues by DXA.[27 28] So, DXA is still not considered to be the "gold standard" method for body fat measurement by some authors.[29 30] On the other hand, recent studies[31 32] have provided evidence that evaluation of body composition by DXA shows high accuracy. In particular, Prior *et al*[31] compared whole body composition estimates using DXA with estimates from a four component model in young adults who varied in gender, race, training status, body size, and musculoskeletal development. They concluded that body composition estimates by DXA were accurate (SEE = 2.8% body weight in %FM estimate).

In some previous studies,[15–17] the authors have compared body composition measurements using DXA, BIA, and skinfold measurement techniques in children and young adults. Ellis[15] measured body composition of 63 males and 36 females with a very large age range (5–22 years). Goran *et al*[16] studied a heterogeneous group of 49 boys and 49 girls, while the group of Gutin *et al* consisted of 21 boys and 22 girls characterised by a large range of body fat percentage.[17] All authors concluded that body composition estimates are highly dependent on method. The usual assumptions in the two compartment model (FM and FFM) with regard to constant hydration and BMC of FFM are probably not valid in groups of children and adolescents of different ages.

To ascertain whether these differences exist in a more homogeneous group, we selected 26 moderately active male adolescents very similar in age, body fatness, and training status.

The purpose of our study was to compare the values of the percentage of FM and the quantity of FFM measured by DXA with those derived from different anthropometric and bioelectrical impedance equations.

Results have shown a mean difference (0.2 kg, $p<0.01$, paired t test) between body weight measured using scales compared with body weight calculated as the sum of the different

masses (FM, SFFT, and BMC) measured with the DXA instrument. Gutin *et al*[17] found that total body mass measured by DXA was significantly lower than the scale weight by slightly less than 1 kg, and Ogle *et al*[14] found that DXA underestimated scale weight by a mean of 0.83 kg, and this was independent of increasing body fat. This mean difference may be a source of error when different FM or FFM estimates obtained by different methods are compared. In our study, body fat percentage was estimated using the equations of Slaughter *et al*[9] and Deurenberg *et al*,[10] and for the calculation of FFM the equations of Houtkooper *et al*,[12] Deurenberg *et al*,[7] Suprasongsin *et al*,[13] and Schaefer *et al*,[11] were used. The calculated values of %FM and FFM (kg) were compared directly with the values measured by DXA.

The equation of Slaughter *et al*[9] is based on an empirically derived multicomponent method, utilising measurement of body density, total body water, and BMC of the radius and ulna. The sample used to develop this equation consisted of children (8–18 years of age) from the United States, with an average %FM of 14.0%, which is slightly higher than our sample (11.7%, DXA value). Moreover, the equation of Deurenberg *et al*[10] for the prediction of %FM was developed using a density value obtained by underwater weighing as the reference method; it was then corrected according to the subject's age, using the formula of Weststrate and Deurenberg[33]. In this formula, it is assumed that the density of the FFM slowly increases with age, from 1.080 g/ml at seven years[34] to 1.100 g/ml at 18 years[35] in both sexes.

In the present study, as in the equation of Deurenberg *et al*,[10] skinfold thickness at several sites was measured on the left side, but this procedure was not used by Slaughter *et al*[9] who utilised the right side. Secondly, age has been shown to account for body density variation beyond that accounted for by skinfold thickness.[36 37] Furthermore, the proposed correction factor[33] used in the formula of Deurenberg *et al*[10] may not accurately reflect the inter-individual variability in body composition. Nevertheless, when compared on the basis of the CV% and the Bland-Altman method,[21] the various methods showed wide differences.

Also, measurement of FFM showed wide variability among the different methodologies used. This is probably due to the different reference methods utilised for the development of the various bioelectrical impedance equations. Suprasongsin *et al*[13] used the dilution technique with deuterium oxide on a group of 56 healthy subjects and patients with various endocrine disorders for the development of their equation. Hewitt *et al*[8] have pointed out that the hydration of the FFM in subjects who have not reached biochemical maturity is extremely variable. Schaefer *et al*[11] utilised FFM values calculated by measuring ^{40}K in 112 healthy children, adolescents, and young adults 3.9 to 19.3 years of age. The concentration of potassium in the tissue of the FFM is known to vary considerably,[38] especially in a group with a wide age range like that of the subjects of Schaefer *et al*.[11] The equation of Houtkooper *et al*[12] was developed using subjects from 10 to 19 years of age and a multicomponent model based on the measurement of density (obtained by underwater weighing) and total body water (deuterium dilution), and from age-corrected density equations which account for variations in FFM in water and BMC. Finally, FFM measured by body density (underwater weighing) corrected for age, using the Weststrate and Deurenberg[33] formula, was used as a reference method in the equation of Deurenberg *et al*.[7]

In conclusion, our results show that, for a group of moderately active adolescents, the three methods (DXA, Slaughter *et al*[9] equation and Deurenberg *et al*[10] equation) can be used interchangeably to measure %FM on a group-mean basis. In contrast, caution should be shown when different techniques are used to calculate %FM and the amount of FFM in adolescents on an individual basis.

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Commentary

This study shows that, even in a very homogeneous group, methods of estimating body composition, be it skinfold measurement or bioelectrical impedance, lack accuracy. The lack of accuracy is found at both the group level and the individual level. This information is not new as it has been shown in many other studies using a less homogeneous study sample. Apart from the question of whether DXA is an appropriate reference method, studies like the present one can only lead to the conclusion that any prediction formula has to be used with care. It cannot be concluded which prediction formula is generally the best and which should not be used.

It may be useful if future comparative studies focus more on the reasons for the difference instead of being only descriptive.

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Br J Sports Med 1998 32: 215-219
doi: 10.1136/bjsm.32.3.215

Notes