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Different Techniques For Body Composition Assessment

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The inter-relationships and alter nativity of body composition variables derived from simple anthropometry [BMI and Skin Folds (SFs) prediction equations] and Bioelectrical Impedance Analysis (BIA) with dual energy x-ray (DXA) of healthy sixty nine children (37 boys and 32 girls) aged 9.24±1.73 years old were evaluated. The children recruited from public schools in Giza governorate. All of them had BMI ranged between 15th and 85th percentile and were assessed for body composition [percentage body fat (%BF), fat free mass (FFM; kilograms) and body fat mass (BFM; kilograms)] using Slaughter Skin Folds (SFs) prediction equations, BIA and DXA. Repeated ANOVA showed significant differences among the three methods used for the studied variables ($p<0.001$). In general, Slaughter and BIA are significantly underestimated measured %BF. There is a high correlation between the BMI and both the estimated %BF and BFM ($r = 0.67$-0.91 for boys and $r = 0.87$ to 0.97 for the girls). Partial correlation among the estimated % BF derived from the three different methods in both genders revealed a high significant correlations between the estimated %BF derived from DXA and Slaughter equations ($r = 0.76$ for boys and 0.97 for girls). While the correlation between the estimated %BF derived from DXA and BIA was 0.77 for boys in contrast to girls where it is low significant correlation ($r = 0.387$). Results suggest that BIA has limited utility in estimating body composition, where as BMI and SFs seem to be more useful in estimating body composition. In conclusion all methods are significantly under estimated body fatness as determined by DXA and the various methods are not interchangeable.

Key words: DXA, BIA, anthropometry, Egyptian children

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INTRODUCTION

Children's body composition had recently received a great attention as a useful and fundamental tool for a careful evaluation of their nutritional and metabolic status (Butte *et al*., 1999; Eisenmann *et al*., 2004; Wells and Fewtrell, 2006; Wang *et al*., 2006; Pietrobelli *et al*., 2007). It can be measured by different methods varying in their sophistication, accuracy, feasibility, cost and availability. Since the body composition is influenced by age and maturation, some procedures are clearly unsuitable for children e.g., under water weighing, others are limited because of availability and cost e.g., Magnetic resonance imaging and dual-energy X-ray absorptiometry (DXA)], while the third offer good feasibility and reasonable cost e.g., Bio-electrical Impedance Analysis (BIA) and formula based on skin fold thickness (Garn *et al*., 1986; Lohman, 1989; Ellis, 1996; Gutin *et al*., 1996; Treuth *et al*., 2001; Fors *et al*., 2002). A major issue in the interpretation of body composition analysis is that different methods may yield different results for the same variable in the same child. However, the value of any approach is greatly enhanced by the availability of the reference data (Cole *et al*., 2002; American Academy of Pediatrics, 2003; Aviva *et al*., 2004).

Among pediatric population, little is known about what is the simple, suitable and more available method used to measure and assess body composition compared with the gold criterion methods such as dual energy x-ray absorpiometry (DXA) as it is the closest representation of true body composition (Aviva *et al*., 2004). So, there is a need to develop an approach where the body composition could be assessed and followed overtime in the individual. Hence, our aim is to investigate the inter-relationships between body composition variables derived from simple anthropometry BMI and Slaughter skin folds prediction equations and Bio-electrical Impedance Analysis (BIA) with dual-energy X-ray absorpiometry (DXA) and to find an alternative method to DXA for assessment of body composition in young Egyptian children that provide insight into accuracy and utility of various methods for measuring the body composition.

SUBJECTS AND METHODS

The participants in the research were sample of Egyptian primary school children (485 boys and 456 girls), aged 7-12 years. The students were recruited from two public schools in Giza governorate, from October, 2003 to April 2004. Permission to perform the study was granted by the Ministry of Education. A local consultation with the directors of schools was done for any concerns and ethical issues of the research. An informed consent form was delivered to the parents or the Legal Authorized Representative (LAR) of National Research Centre for their approval and signatures prior the conduction of the research. The order of the procedures was as follows: a questionnaire, anthropometry, BIA, general overview of the study and DXA.

A questionnaire was designed to collect personal, social and medical data from each child. Those having chronic disease or any situation that impair their normal growth were excluded. The socioeconomic status of the student was characterized by scoring the parental educational level, occupation and crowding index and only the medium leveled students were enrolled in this study (the majority of the students in these two public schools).

Anthropometric measurements for each student were attempted including body weight (Wt), body height (Ht) and skin fold thickness at triceps and sub scapular areas, following the recommendations of the International Biological program (Hiernaux and Tanner, 1969). Three consecutive readings were obtained for each measurement; by one researcher and another one assisted to him, who was well trained on performing these measurements before starting this piece of research and the mean was recorded. The body weight was measured using a standardized Seca Beam balance to the nearest 10 g with minimal clothes for which no correction was made. The body height was measured using Holtain portable anthropometer to the nearest 0.1 cm. The BMI ($kg\ m^{-2}$) was derived and accordingly the children were classified to exclude those below 15th and above 85th percentiles (malnourished), so the normal children only (429 boys and 390 girls) continue in the study. Triceps and sub scapular skin fold thickness were measured using Holtain Caliper to the nearest 0.2 mm and their sum was calculated.

When the sum of skin fold thickness was below 35 mm, percentage body fat (% BF), Fat Free Mass (FFM) and Body Fat Mass (BFM) were calculated for each student by the following equations according to Slaughter (1988):

Estimated body fat % (%BF)

For boys: $\%BF = 1.21\ (TRI + Subscap\ SF) - 0.008\ (TRI + Subscap\ SF)^2 - 1.7$

For girls: $\%BF = 1.33\ (TRI + Subscap\ SF) - 0.013\ (TRI + Subscap.\ SF)^2 - 2.5$

Fat-free-mass (FFM): $FFM = Wt.-(Fat\ \% /100.\ Wt.)$ kg

Body Fat Mass (BFM): $BFM = Wt.-FFM$ (kg)

BIA: Whole body resistance and reactance (capacitance) were measured using a bioelectrical impedance analyzer (HOLTAIN LIMITED). As specified by the manufacturer, the unit was calibrated before testing using 400-ohm resistor and electrodes were placed on wrist and ankles. By using child sex, age, weight and height approximated to the nearest unit, the BFM, %BF and FFM were derived.

As a general overview of the study, the estimated % BF and BFM by Slaughter equations and BIA in evaluation of body composition of school children were investigated using Pearson's correlation tests. Highly significant correlations were found ($p>0.001$).

Then, DXA was used as a criterion measure for 69 children: 37 boys and 32 girls (those only who respond to our recall) for its availability and cost. Whole body DXA scans were performed using a Lunar DPX-L densitometer (Lunar Radiation Corporation, Madison, WI) with the child in minimal clothing while lying supine. The DXA machine creates a series of transverse scans by directing a very weak, but focused, pencil beam X-ray systematically inch-by-inch across the child's body differentiating the body tissue into bone mineral, lean mass (non bone) and fat mass. In this study, % BF, BFM and FFM were determined using the pediatric medium scan mode (software version 1.5D).

Quality control procedures were followed in accordance with manufacture's recommendations. Routine daily calibration was done using the standard applied by the manufacture.

Data analysis: Descriptive statistics (mean±standard deviation) were calculated for the anthropometric and body composition measures and independent student's t-tests were carried out to examine sex differences. The difference between the mean values of the body composition variables (%BF, FFM, BFM) derived from the three different methods (Slaughter equations, BIA and DXA) in both genders were calculated by repeated measures ANOVA. To eliminate age factor, partial correlation was attempted to investigate the interrelationships between the different body composition variables.

The Bland-Altman procedure was used to examine the pair-wise comparison between %BF measured by DXA and the other methods (BIA and Slaughter equation). Error score were computed by subtracting the estimated values (% BF derived from Slaughter and BIA) from the criterion value DXA. One sample Student's t test was performed to examine whether the mean error scores were significantly different from zero. These error scores were also graphically illustrated according to the procedures of Bland and Altman (1986) and were plotted against the mean value of the two respective methods e.g., (DXA+BIA)/2. The mean error scores were illustrated by a solid horizontal line. Statistical analysis was conducted using SPSS version 10 for windows (Statistical Package for Social Sciences). The charts were drawn using Microsoft Excel software.

RESULTS

Physical characteristics of the sample showed no significant gender difference regarding the age (9.06 for boys and 9.36 for girls), anthropometric and body composition measures (Table 1).

Repeated measures ANOVA of the estimated body composition variables (%BF, FFM, BFM) derived from the three different methods (Slaughter, BIA, DXA), showed a significant differences among the three methods for the studied variables ($p<0.001$). In both genders, it is obvious that the BIA methods significantly showed the least values for the estimated %BF and BFM, consequently the highest values were seen in the FFM, followed by Slaughter equation, then by DXA for both sexes (Table 2, 3).

Bland-Altman plots: The overall mean difference and 95% confidence intervals for each body composition method were as follow. BIA was 5.82 (3.26, 8.39), 9.78 (6.88, 12.68) for boys and girls respectively and 7.66 (5.73, 9.59) for the total sample. Regarding Slaughter values, it was 4.05 (1.79, 6.30) for boys and 3.29 (2.74, 3.84) for girls while the total sample was 3.70 (2.48, 4.91). The two methods used (Slaughter, BIA) are significantly under estimated measured percentage body fat (%BF) where $p<0.001$ (Fig. 1).

Partial correlations between BMI and body composition variables (%BF, BFM and FFM) derived from various methods were significant in both genders ($p<0.05$, $p<0.001$). In general, correlations between the BMI and both estimated %BF and BFM were strong (for boys $r = 0.67$-0.91 and for girls $r = 0.87$-0.97, $p<0.001$) except with those estimated by BIA for girls, the correlation was moderate ($r = 0.56, 0.62$, $p<0.001$). The lowest correlations (weak to moderate) were recorded between BMI and estimated FFM (for boys $r = 0.34$ to 0.46 and for girls $r = 0.20$-0.56, $p<0.001$) except for FFM-DXA, the correlation was insignificant for girls (Table 4).

Partial correlation among the estimated body fat percentage derived from the three different methods for both genders, revealed high significant correlations between the estimated % BF derived from DXA and

Table 1: Physical characteristics of the sample

	Boys (n = 37)	Girls (n = 32)	
Characteristics	Mean±SD	Mean±SD	(p)
Age (years)	9.06±2.16	9.36±1.29	NS
Weight (kg)	31.99±10.90	31.80±8.39	NS
Height (cm)	133.10±15.69	134.60±10.56	NS
BMI (kg m^{-2})	17.53±2.79	17.23±2.42	NS
TSF (mm)	9.86±6.48	11.72±4.86	NS
Subscapular SF (mm)	9.67±5.04	9.63±4.12	NS
SUM	18.93±11.28	21.34±8.39	NS

Table 2: Comparison of body composition measured by Slaughter equations, BIA and DXA in boys (n = 37)

Parameters	% BF	BFM	FFM
Slaughter	17.56±8.91	6.11±5.17	25.89±8.04
	8.75-45.92	1.68-23.88	16.23-46.65
BIA	15.79±11.47	5.95±5.87	26.02±6.48
	3.11-43.83	0.68-22.79	17.00-38.18
DXA	21.61±10.42	6.53±3.90	22.21±8.36
	9.90-48.90	3.10-20.96	10.25-51.28

Values represent mean±SD and minimum-maximum. Significant differences among methods were proved by ANOVA test (p<0.001)

Table 3: Comparison of body composition measured by Slaughter equations, BIA and DXA in girls (n = 32)

Parameters	% BF	BFM	FFM
Slaughter	19.08±7.09	6.49±3.37	25.31±5.36
	6.17-27.23	1.35-11.71	18.94-32.92
BIA	12.59±9.64	4.62±4.52	27.19±5.13
	3.01-35.05	0.68-15.14	18.08-35.00
DXA	22.37±7.25	7.01±3.53	22.17±4.81
	10.65-33.10	2.15-12.65	16.15-33.26

Values represent mean±SD and minimum-maximum. Significant differences among methods were proved by ANOVA test (p<0.001)

Table 4: Partial correlations, controlling for age, between the BMI and body composition measures in both sexes

		BMI	
Parameters		Boys	Girls
Slaughter	% BF	0.879**	0.871**
	BFM	0.907**	0.966**
	FFM	0.340*	0.559**
BIA	% BF	0.763**	0.564**
	BFM	0.847**	0.616**
	FFM	0.461**	0.531**
DXA	% BF	0.827**	0.909**
	BFM	0.675**	0.881**
	FFM	0.416**	0.196

All correlations were significant (**: p<0.001, *: p<0.05) except with DXA-FFM in girls

Table 5: Partial correlations, controlling for age, among body composition measures in both sexes

Parameters		% BF-Slaughter	% BF-BIA	% BF-DXA
% BF- Slaughter	r	-	0.284	0.971**
	p	-	0.122	0.000
% BF- BIA	r	0.730**	-	0.387*
	p	0.000	-	0.031
% BF-DXA	r	0.763**	0.772**	-
	p	0.000	0.000	-

Upper, girls; lower, boys. *: p<0.005, **: p<0.001

Slaughter methods where r = 0.763 for boys and 0.971 for girls. As regard the correlation between the estimated % BF derived from DXA and BIA showed a high significant correlation (r = 0.772) for boys and low significant correlation (r = 0.387) for girls. Also, the estimated % BF derived from BIA and Slaughter methods showed a high significant correlation (r = 0.730) for boys and low insignificant correlation (r = 0.284) for girls (Table 5).

DISCUSSION

Human body composition, particularly the content of fat tissue and its distribution, has been extensively measured in healthy, diseased and obese subjects (Nancy *et al*., 2000). A variety of non-invasive methods have been applied for these studies (Bolanowski and Nilsson, 2001). Skin fold thickness prediction equations and bioelectrical impedance (BIA) are readily available and commonly used techniques in patient monitoring for Body Composition Analysis (BCA) in clinical practice (Erselcan *et al*., 2000). Bioelectrical impedance analysis (BIA) is a commonly used method, based on the conduction of electrical current in the body and the differences in the ability to conduct electricity between the fat and water components of the body. Recently, dual-energy x-ray absorptiometry (DXA) has been introduced for bone mass, bone mineral density and body composition studies. Unlike other methods, DXA measures three components of the body: bone mineral content, fat tissue mass and lean tissue mass and additionally regional fat distribution. Despite some minor bias, DXA is considerably less expensive and easier to administer in pediatric subjects than other established gold standard reference methods for assessing body composition (Pietrobelli *et al*., 2003). Its results have been reported to be quite accurate and precise, in comparison with *in vivo* or *in vitro* multiple component reference methods (Erselcan *et al*., 2000).

This research provides an evidence of convergent validity for various methods and prediction equations of body composition in young children across the primary school age range which considered as a critical period for the adiposity development. Furthermore, the results will provide insight into the ability to compare results between studies using different body composition methodologies. Overall, the %BF and BFM estimated by the Slaughter prediction equations show high correlations among themselves and the BMI (r = 0.88 to 0.91 for boys and r = 0.87 to 0.97 for girls) and those estimated by DXA show similar correlations (r = 0.68 to 0.83 for boys and r = 0.88 to 0.91 for girls), while the BIA estimates of %BF and BFM show high correlations for boys (r = 0.76 to 0.85) and moderate for girls (r = 0.56 to 0.62). Furthermore, Partial correlation among the estimated body fat percentage derived from the three different methods,

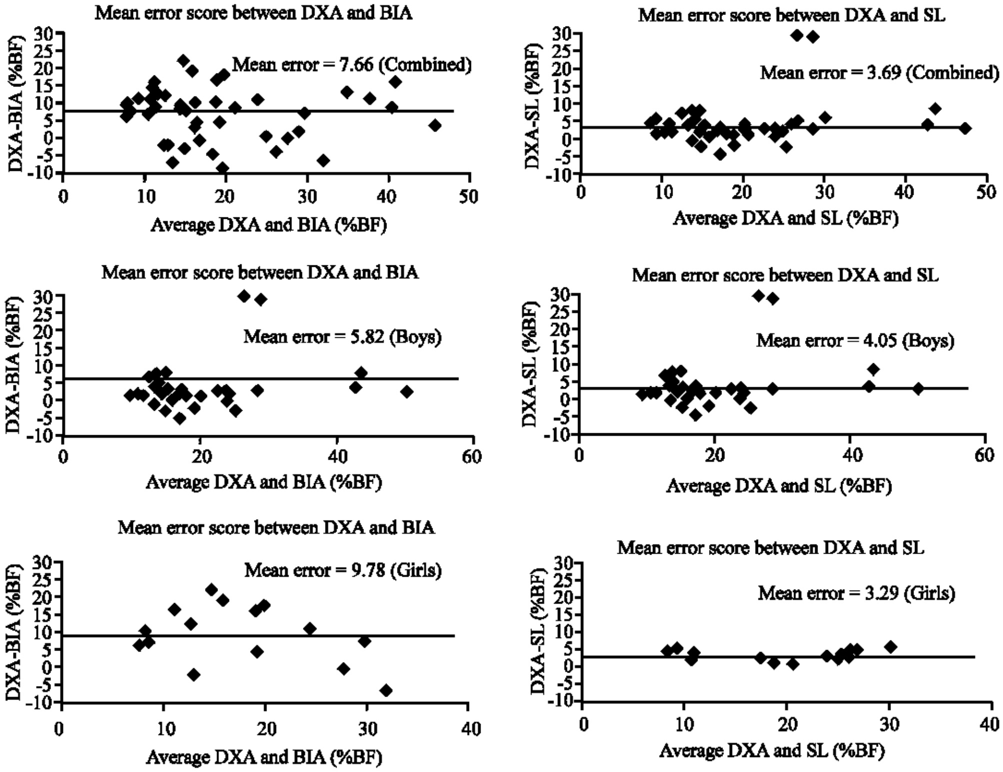

Fig. 1: Bland Altman tests depicting error scores between DXA and the various measures and estimates of percentage of BF. The solid line represents the mean error

revealed high significant correlations between the %BF estimated by DXA and those estimated by Slaughter prediction equations for both genders and by BIA for boys only ($r = 0.73$ to 0.97, $p<0.001$)). However, for girls, the BIA estimates of %BF exhibited low correlation with DXA ($r = 0.39$, $p<0.05$) and insignificant correlation with % BF- Slaughter ($r = 0.28$). Despite the moderate to high correlations among methods, results comparing the mean values from the different methods or Slaughter prediction equations revealed some systematic error. All methods were found to be significantly underestimating the values of %BF from DXA. The mean bias ranged from 4.1 to 5.8 for boys, from 3.1 to 9.8 for girls and from 3.7 to 7.7 for the total sample.

In this study, larger discrepancies were found with the BIA procedure. It appears that the discrepancy in the BIA measures is a function of weight status. As indicated in Fig. 1, BIA underestimated %BF from DXA in boys tended to be leaner or fatter and in girls tended to be leaner. At the same time, it overestimated %BF in girls tended to be fatter. This can also be seen in the range of values (Table 2, 3). BIA showed the lowest minimum and maximum values for %BF in boys and the lowest minimum and highest maximum values for %BF in girls compared with the other methods. These results are in agreement with others that show a high bias in %BF between BIA and DXA. For example, Treuth *et al.* (2001) found a mean bias of 7.6% with limits of agreement of 7.6% in prepubertal girls. Eisenkolbl *et al.* (2001), in Austria, concluded that %BF measured by BIA compared to DXA method in 6-18 years old obese children is three times higher with boys than with girls. The reverse was estimated in other studies on prepubertal children in Japan and USA (Okasora *et al.*, 1999; Elberg *et al.*, 2004) where they stated that change in %BF was systematically overestimated by BIA equations. While, Sun *et al.* (2005) in Canada, stated that BIA is a good alternative for estimating %BF when subjects are within a normal body fat range. BIA tends to overestimate %BF in lean subjects and underestimate %BF in obese subjects.

In general, Slaughter prediction equations also underestimated %BF from DXA in both sexes of this sample. However, the overall results for anthropometric indices of adiposity (i.e., BMI and Skin folds prediction equations) are encouraging because the techniques are relatively simple (assuming proper training), cost effective and widely used. Specifically, the results show that Slaughter prediction equations can be used with reasonable accuracy to monitor the age-related changes in body composition during the adiposity rebound. The errors in BF estimates that were observed are not surprising considering that the adiposity rebound may be an artifact of growth in FFM, as indicated by the association between BMI and DXA FFM where the lowest correlations were recorded between BMI and estimated FFM (for boys r = 0.34 to 0.46 and for girls r = 0.20 to 0.56, p<0.001 except for FFM-DXA, the correlation was insignificant for girls). The subjects here represented the spectrum of ages in which the adiposity rebound occurs. Although the adiposity rebound is represented by the change in the BMI, the change in skin folds also indicates somewhat of a rebound (Tanner, 1962; Malina *et al*., 2003). Overall, the BMI, Slaughter prediction equations and DXA show similar correlations (r = 0.83 to 0.88 for boys and r = 0.87 to 0.91 for girls). These results suggest that the BMI and skin folds data prediction equations may represent the adiposity rebound reasonably well.

Some comment should be made regarding the Slaughter prediction equations used here. Overall, the Slaughter prediction equations show high correlations among the other methods (r = 0.88 to 0.91 for boys and r = 0.87 to 0.97 for girls). The equation of Slaughter *et al.* (1988), used in this research is suitable as it is a common equation used in the pediatric literature and were derived from 8- to 18-year-old subjects. On other hand, Dezenberg *et al.* (1999), stated in their study of body composition prediction from anthropometry in preadolescent children that the Slaughter prediction equations were not valid even though the correlation between Slaughter prediction equations-BFM and DXA-BFM as 0.90. It is important to remember that skin fold thicknesses represent subcutaneous fatness at selected anatomical sites; therefore, one would not expect a correlation much higher than that found here.

These results suggest that BIA has limited utility in estimating body composition, whereas BMI and Slaughter prediction equations (derived from skin fold thickness) seem to be more useful in estimating children body composition. So, when DXA is not available, use of Slaughter in estimating body composition is more informative than BIA. However, all methods significantly underestimated body fatness as determined by DXA. These findings, along with rather large limits of agreement derived from the Bland-Altman procedure, suggest that the methods should not be used interchangeably. This was supported by other studies in different countries (Gutin *et al*., 1996; Ellis, 1996; Eisenmann *et al*., 2004; Fors *et al*., 2002; Minderico *et al*., 2007).

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