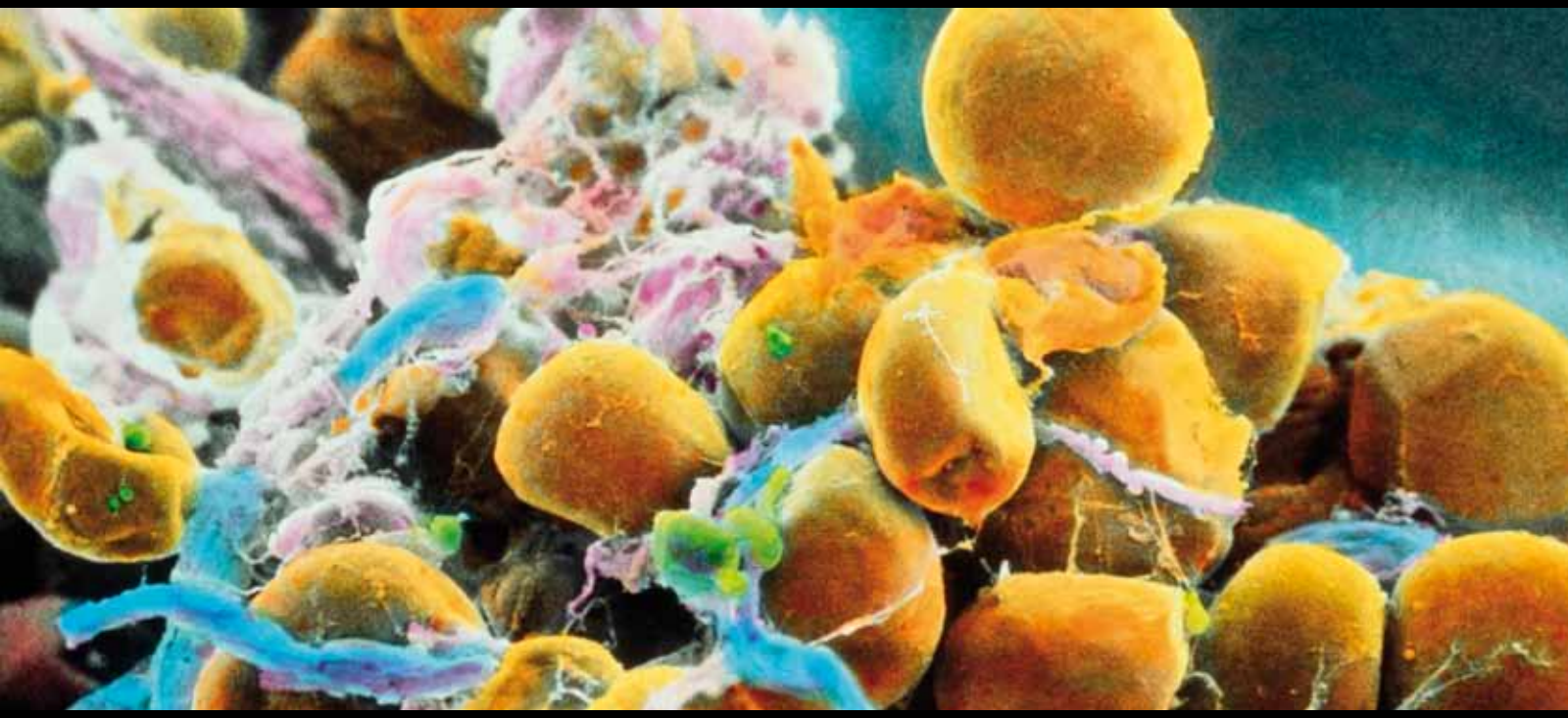
Journal of Obesity

Body Composition: Assessment, Regulation, and Emerging Techniques

Guest Editors: Analiza M. Silva, David A. Fields, Diana Thomas, and Boyd J. Strauss



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Editorial Board

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Editorial

Body Composition: Assessment, Regulation, and Emerging Techniques

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Advances in body composition measurement, evaluation, and analysis have contributed vastly to our knowledge of human biology. These advances can be organized into three distinct, interconnected areas: body composition paradigms, body composition methodology, and body composition response to external influences. The first research area describes the architecture of human body composition identifying proportions of various compartments and their steady-state associations among the atomic, molecular, cellular, tissue system, and whole-body levels; the second research area investigates the merits of different body composition measurement methods for *in vivo*; and the third investigates the response of body composition to factors such as growth and aging.

The five-level model proposed by Z. Wang et al. in 1992 was an important advancement towards building an appropriate structure for body composition research by organizing components into five distinct levels of increasing complexity: atomic, molecular, cellular, tissue system, and whole-body.

The eight articles that appear in this special issue are categorized with some overlap into these three main research areas. The review paper proposed by A. M. Silva et al. provides the relationship between body composition architecture and methodology research. The authors discuss the assumptions of hydrometric and densitometric two-component models, namely, 73.2% and 1.1 g/cc for the fat-free mass (FFM) hydration and density, correspondingly. These averages do not include interindividual variability in FFM, particularly in the pediatric population. The review highlights the need for multicomponent models for more accurate body composition assessment in children. To meet this need, the authors reviewed skinfolds and bioelectrical impedance-based predictive equations developed using multicomponent models for use as a reference method.

In general, development of methodology, methodology evaluation, and methodology validation was the main focus of one review and three original papers. These articles develop mathematical formulae derived from statistical analysis of experimental observations. At the whole-body level of analysis, A. F. Casey reviewed assessment validity and reliability in individuals with intellectual disability. D. Machado et al. proposed new anthropometric-based equations to assess bone mineral, lean soft tissue, and fat mass for a male pediatric population. E. Forsum et al. analyzed the relationship between body mass index and body fat assessed by air displacement plethysmography in 4-year-old children. At the tissue level of analysis, W. Shen et al. compared bone marrow fat measurements among T1-weighed magnetic resonance imaging (MRI) and magnetic resonance spectroscopy. E. L. Rolfe et al. analyzed the validity of ultrasound visceral and subcutaneous abdominal depth as a proxy for MRI measured internal abdominal and subcutaneous fat in infants.

Finally, in the last research category, two original papers investigated body composition response to aging and ethnicity. M. F. Almeida et al. examined longitudinal anthropometric changes in Brazilian older adults from 2000 to 2006. C. L. Carpenter et al. evaluated the efficacy of the body mass index (BMI) as a proxy for adiposity across different ethnic groups by comparing to measured percent body fat. The research field investigating body composition responses also includes responses to growth, development, nutrition, exercise, hormonal changes, and medication. In this regard, the study of the dynamic relations between body components and its associate's functions has been recently explored. A large body of research evaluating body composition responses to these factors at both the experimental and theoretical levels is now available. In fact, the concept of functional body composition has been proposed, providing more sophisticated view of nutritional status, metabolism, endocrinology, and diseases. More than just the assessment of the compartments in any of these five levels, functional body composition addresses the quantitative and biological interactions of these compartments with energy balance status, metabolic features, healthy and unhealthy biomarkers, sports performance markers, and many other measurable physiological expressions of a living organism.

In conclusion, the original research and reviews contained in this special issue identify gaps and provide potential alternatives to more accurate routine body composition assessment in basic science and clinical settings. From a clinician's perspective, these papers mostly tell us about body composition models, techniques, and assessment in health across the age span, with the underlying assumption of steady state. However, these papers do not address how robust these techniques are in a nonsteady state (i.e. clinical illness). This is important in an obesodiabetogenic environment that appears to hit all corners of the world. This aspect is also intimately linked to the functional aspects of body composition where a key question is the nature and the extent of pathophysiological influences on body composition changes, on the one hand, and the effect of those body composition changes on pathophysiology on the other hand. What these papers do is to help in setting a modern scene for interpreting clinical findings, though more research is needed to capture the longitudinal body composition response and related energy regulation during clinical illness, growth, and aging, as well as the effect of diet and exercise interventions.

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Review Article

A PRISMA-Driven Systematic Review of Predictive Equations for Assessing Fat and Fat-Free Mass in Healthy Children and Adolescents Using Multicomponent Molecular Models as the Reference Method

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Simple methods to assess both fat (FM) and fat-free mass (FFM) are required in paediatric populations. Several bioelectrical impedance instruments (BIAs) and anthropometric equations have been developed using different criterion methods (multicomponent models) for assessing FM and FFM. Through childhood, FFM density increases while FFM hydration decreases until reaching adult values. Therefore, multicomponent models should be used as the gold standard method for developing simple techniques because two-compartment models (2C model) rely on the assumed adult values of FFM density and hydration (1.1 g/cm^3 and 73.2%, respectively). This study will review BIA and/or anthropometric-based equations for assessing body composition in paediatric populations. We reviewed English language articles from MEDLINE (1985–2012) with the selection of predictive equations developed for assessing FM and FFM using three-compartment (3C) and 4C models as criterion. Search terms included children, adolescent, childhood, adolescence, 4C model, 3C model, multicomponent model, equation, prediction, DXA, BIA, resistance, anthropometry, skinfold, FM, and FFM. A total of 14 studies (33 equations) were selected with the majority developed using DXA as the criterion method with a limited number of studies providing cross-validation results. Overall, the selected equations are useful for epidemiological studies, but some concerns still arise on an individual basis.

1. Introduction

The rise in the prevalence of childhood obesity [1] has precipitated the need for simple but accurate methods for determining adiposity in paediatric populations. The adolescent years are a period of rapid growth in both the fat (FM) and fat-free mass (FFM) compartments. Despite the recognized importance of measuring body composition in paediatric population, there are a limited number of valid methods that can be used in both clinical and field settings. Most of the simple methods used were developed using the two-compartment (2C) model as the criterion method [2]. The 2C model divides body weight into FM and FFM, relying on assumptions that ignore interindividual variability in the FFM composition, which is the most heterogeneous of the two depots (especially in growing children). Consequently, measured values of FM and FFM are method dependent [3], making accuracy difficult to assess while hindering comparisons across different methods and studies. Multicomponent models, such as 3C and 4C approaches, are robust to interindividual variability in the composition of the FFM [4]. The model divides body weight into fat, water, mineral, and protein and allows evaluation of several assumed constant relations that are central to 2C models. Although reference data exist for these constants in children from birth to 10 y of age [5], most values were predicted by extrapolating data between infants (6 months) [5] and the 9-year-old reference child [5, 6].

The lack of accurate data on body composition further hinders the evaluation of simple field-based techniques

such as bioelectrical impedance analysis (BIA) and simple anthropometric measurements. Collectively, these body composition tools are the most commonly used methods in children and adolescents. Variables obtained from BIA and anthropometry are often used as predictors during regression analysis aimed to developed FM and FFM equations based on criterion methods. Given the vast number of BIA and anthropometric-based equations for body composition assessment in children and adolescents, it is difficult to select the most appropriate solution. Therefore, clinicians and health-related professionals need specific and detailed criteria for the appropriate model to select, paying close attention to methodological-, biological- and statistical-related issues that will impact the validity of the body composition value obtained.

1.1. Methodological Considerations. In 1992, Wang et al. [7] proposed an interesting system to organize the human body composition, the five-level model. Based on this approach, the human body was characterized in terms of five levels: atomic, molecular, cellular, tissue, and whole body. Most of the methodological research in human body composition analysis has been conducted at the molecular level. Some of the most widely used molecular level models divide body mass into two, three, or four components. As suggested by Wang et al. [8], methods of quantifying these components *in vivo* can be organized using the following general formula:

$$C = f(Q), \tag{1}$$

where C represents an unknown component, Q a measurable quantity, and f a mathematical function relating Q to C [8]. The mathematical function used in the aforementioned formula can be classified into two types. The first is referred Type I and was developed using a reference method and regression analysis of data to derive the predictive equation [8]. In these cases, a reference method is typically used to measure the unknown component in a group of participants with certain characteristics. The measurable quantity (Q, i.e., property and/or the known component), as defined in the general formula, is also estimated. Regression analysis is then used to establish the mathematical function (f) and thus, develop the equation that predicts the unknown component [8]. The second type of mathematical function, known as Type II, is based on firmly founded models. These models usually represent proportions or ratios of measurable quantities to components that are assumed constant within and between subjects [8]. Indeed Type II methods are based on assumptions required for their development, and several models have been published. Generally, these models were developed from simultaneous equations, which may include two or more unknown components and/or the measurable property. The less complex Type II methods are based on a 2C model where body mass is divided into FM and FFM, either from hydrometric or densitometric techniques. Type II methods can be described as any of the following combinations.

(i) *Two-compartment model*:

$$\text{Body Mass} = \text{fat} + \text{fat-free mass}, \tag{2}$$

see [2].

(ii) *Three-compartment model*:

$$\text{Body Mass} = \text{fat} + \text{water} + \text{residual}, \tag{3}$$

that is, the sum of protein, minerals, and glycogen [9]:

$$\text{Body Mass} = \text{fat} + \text{bone mineral} + \text{residual}, \tag{4}$$

that is, the sum of protein, water, and glycogen [10],

$$\text{Body Mass} = \text{fat} + \text{bone mineral} + \text{lean soft tissue}, \tag{5}$$

see [11].

(iii) *Four-component model:*

$$\text{Body Mass} = \text{fat} + \text{water} + \text{bone mineral} + \text{residual}, \tag{6}$$

that is, the sum of protein, soft tissue minerals and glycogen [12, 13],

$$\text{Body Mass} = \text{fat} + \text{water} + \text{bone mineral} + \text{protein} \tag{7}$$

[14, 15].

(iv) *Five-component model:*

$$\begin{aligned}\text{Body Mass} = {} & \text{fat} + \text{water} + \text{Bone mineral} \\ & + \text{Soft tissue mineral} + \text{residual},\end{aligned} \tag{8}$$

that is, the sum of protein and glycogen [16].

(v) *Six-component model:*

$$\begin{aligned}\text{Body Mass} = {} & \text{fat} + \text{water} + \text{Bone mineral} \\ & + \text{Soft tissue mineral} + \text{protein} + \text{glycogen},\end{aligned} \tag{9}$$

see [17].

The densitometric method requires the assessment of body volume (BV), usually estimated by hydrostatic weighing or air displacement plethysmography, serving as the basis for 2C model of body composition analysis. The addition of total-body water (TBW) is allowed for the development of 3C molecular models [9]. The derived 3C model accounted for the variation in subject hydration by adding a TBW estimation using dilution techniques to Behnke's 2C model [2]. On the basis of data available at the time from five chemically analyzed human cadavers, Siri [9] assumed that FFM consisted of two molecular level components, TBW and a combined protein and total mineral [M, that is, the sum of soft tissue minerals and bone mineral (M_o)] residual component. To complete the model, Siri suggested a constant ratio between mineral and protein of 0.35, as estimated from the five cadavers, with a corresponding density of 1.565 kg/L.

Dual energy X-ray absorptiometry (DXA) has the advantage of being a 3C model that quantifies total and regional fat mass, lean soft tissue, and bone mineral content. This

method assumes that nonosseous tissue consists of two distinct components, fat and lean soft tissue [11]. The lean soft tissue component is the difference between body weight and the sum of fat and bone mineral ash. Fat and lean components are quantified over regions devoid of bone. Typically, the energy source produces photons at two different energy levels, 40 and 70 keV, which pass through tissues and attenuate at rates related to its elemental composition. Bone is rich in highly attenuating minerals, calcium, and phosphorous and is readily distinguished from soft tissues [11]. The measured attenuation of DXA's two main energy peaks is used to estimate each pixel's fraction of fat and lean according to series of physical models [11]. Overall, the DXA method for estimating three components is first, to separate pixels into those with soft tissue only (fat + lean soft tissue) and those with soft tissue + bone mineral, based on the two different photon energies (lower and higher energies, resp.). DXA quantifies FM and FFM with precision [18–21] and provides accurate measures when compared to multicomponent models [22–26]. Indeed, scanning speed and minimal-risk allowed its wide implementation and usage in large multicenter studies, including the National Health and Nutrition Examination Survey [27, 28].

The 3C molecular model of Siri [9] can then be extended to a 4C molecular model by adding an estimate of bone mineral by DXA. The 4C model provides the criterion measurements for body composition assessment [29], but its cost, time involvement, poor subject compliance in pediatric populations, and sophisticated technological analysis are impractical for most, if not all nonresearch-based settings. In fact, the 4C model, which divides body mass into FM, water, mineral and protein (and/or residual), is considered the state-of-the art method for assessing body composition as it can accurately account for the variability in the FFM composition [30]. This model involves measurements from different techniques thus allowing the evaluation of several assumed constant relations that are central to 2C models. However, one of the limitations of estimating body fatness from multicomponent models is that combined technical errors occur when each component is separately estimated. While a higher validity is expected with the measurement of more components, there is an associated propagation of measurement errors with the determination of body density (or volume), TBW, and bone mineral. Nevertheless, as long as technical errors are relatively small in each of these components, the cumulative error is also relatively small. Still, when one or more of these components is not precisely measured, the advantages of multicomponent analysis are decreased [29]. Finally, the addition of *in vivo* neutron activation analysis is required to assess soft-tissue minerals and glycogen extending FM estimation from a 4C model to 5C and 6C molecular models.

1.2. Biological Considerations. There are many biological conditions where the study of multiple components within the FFM composition is important [30]. Measuring multiple components often reduces the errors of the assumptions in Type II methods specifically in pediatric populations that can vary substantially the contribution of main FFM components due to growth and maturation. As previously stated, 2C models, use either hydrometric or densitometric techniques and are based upon constants that came from a few adult human cadaver dissections, animal data, and indirect estimates of FFM in human subjects [9, 31, 32]. This approach is less accurate in children because of potential changes in the various assumptions of 2C models during growth and maturation, such as changes in the density and hydration of the FFM [10]. Therefore, the 4C model is robust to interindividual variability in the FFM and is the "gold standard" in pediatric populations [33]. However, multicomponent models are costly, time consuming, and impractical for most settings. For example, to assess FM, a typical 4C model study requires many hours for completion, normally starting with isotope dilution for TBW and measurement of body mass. Then, underwater weighing or air displacement plethysmography and DXA techniques, respectively, for body volume and bone mineral assessment are needed. Two measurable quantities, TBW and bone mineral along with two properties, body volume and mass, are required to calculate FM.

An alternative solution in overcoming the lack of accuracy using less complex techniques based upon 2C models is the use of age- and sex-specific constants derived from pediatric populations. Hydrometry and densitometry are two techniques widely used to assess pediatric body composition due to their ease of application, but their validity depends on the accuracy of age- and sex-specific constant values for FFM hydration or density. Since 1980, these constants have relied upon empirical data from Fomon et al. [5] that published body composition values for a reference child starting at birth going to 10 y, with most of the values extrapolated from other data [34]. Lohman [10] provided similar reference data for pediatric ages based on simultaneous measurements of TBW, body density, and forearm bone mineral density [34, 35]. Simulations for adolescents were also reported by Haschke [6]. Based on these studies and extrapolations, Table 1 presents sex- and age-specific constants for conversion of body density, water, and mineral to percent fat in children and adolescents.

Recently, Wells et al. [33] reported reference data for the hydration and density of the FFM and developed prediction equations on the basis of age, sex, and body mass index standard deviations using the 4C measures obtained in a large, healthy sample of children and adolescents aged 4–23 years. Table 2 represents the median values proposed by the authors for hydration, density, and constants using the LMS (lambda-mu-sigma) method. Using these values it is possible to substitute C1 and C2 constants in Siri's [9] equation, thus, improving the accuracy of densitometric techniques in estimating FM of a healthy pediatric population.

In addition, the age- and sex specific constants for FFM hydration presented in Table 2 can be used to improve the accuracy of hydrometric methods known to be based on the following stable relationship:

$$\mathrm{FFM}\,(\mathrm{kg}) = \mathrm{FFM}_{\mathrm{TBW}} * \mathrm{TBW}\,(\mathrm{kg}), \tag{10}$$

Table 1: Age- and sex-specific constants for conversion of body density, water, and mineral to %FM in children and youth.

Age (years)	Females			Males		
	D_{FFM}	$C1$	$C2$	D_{FFM}	$C1$	$C2$
7–9	1.079	5.451	5.052	1.081	5.400	4.996
9–11	1.082	5.376	4.968	1.084	5.327	4.914
11–13	1.086	5.279	4.861	1.087	5.255	4.835
13–15	1.092	5.141	4.708	1.094	5.098	4.660
15–17	1.094	5.098	4.660	1.096	5.055	4.612
17–20	1.095	5.076	4.636	1.099	5.002	4.554
20–25	1.096	5.055	4.612	1.100	4.971	4.519

%FM: percent fat mass; Db: body density; D_{FFM}: fat-free mass density; $C1$: constant 1; $C2$: constant 2.
*Calculation of percent fat mass (%FM) using age- and sex-specific values for the density of the FFM: %FM = $[(C1/\text{Db}) - C2] * 100$, where Db represents body density. Adapted from Lohman [10].

Table 2: Median values for hydration, density, and constants ($C1$ and $C2$) for the paediatric version of Siri's (11) equation, obtained by using the LMS (lambda-mu-sigma) method*.

Age	Males				Females			
	Hydration %	Density kg/L	$C1$	$C2$	Hydration %	Density kg/L	$C1$	$C2$
5 y	76.5	1.0827	5.36	4.95	76.7	1.0837	5.33	4.92
6 y	76.3	1.0844	5.32	4.90	76.1	1.0865	5.27	4.85
7 y	76.1	1.0861	5.28	4.86	75.5	1.0887	5.22	4.79
8 y	75.9	1.0877	5.24	4.82	75.2	1.0900	5.19	4.76
9 y	75.7	1.0889	5.21	4.79	75.1	1.0909	5.17	4.74
10 y	75.5	1.0900	5.19	4.76	75.0	1.0916	5.15	4.72
11 y	75.3	1.0911	5.16	4.73	75.0	1.0924	5.13	4.70
12 y	75.2	1.0917	5.15	4.72	74.9	1.0937	5.10	4.67
13 y	75.0	1.0920	5.14	4.71	74.6	1.0954	5.07	4.63
14 y	74.8	1.0927	5.13	4.69	74.4	1.0975	5.02	4.58
15 y	74.4	1.0942	5.09	4.66	74.1	1.0996	4.98	4.53
16 y	74.0	1.0960	5.05	4.61	73.8	1.1011	4.95	4.49
17 y	73.7	1.0978	5.02	4.57	73.7	1.1020	4.93	4.47
18 y	73.5	1.0991	4.99	4.54	73.6	1.1027	4.92	4.46
19 y	73.4	1.1000	4.97	4.52	73.6	1.1031	4.91	4.45
20 y	73.3	1.1006	4.96	4.51	73.6	1.1035	4.90	4.44

*$C1$ is calculated as $(D_{FFM} * D_{FM})/(D_{FFM} - D_{FM})$, and $C2$ is calculated as $D_{FFM}/(D_{FFM} - D_{FM})$; D_{FFM} and D_{FM} represent fat-free mass density and fat mass density, respectively. % fat mass is calculated as $[(C1/\text{Db}) - C2] * 100$, where Db is measured body density. Adapted from Wells et al. [33].

where FFM_{TBW} stands for fat-free mass hydration based on the age- and sex-specific constants and TBW for total body water. This equation can be rearranged to

$$\%FM = \left(\frac{FM}{BM}\right) * 100, \quad (11)$$

where FM is assessed from subtracting FFM from body mass (BM). It is important to emphasize if adult values are used rather than the proposed age- and sex-specific constants in the estimation of FM from densitometric and hydrometric methods, an over- and underestimation of adiposity is expected, respectively. In fact, Siri's 3C model by including both TBW and density is a valid model for determining FM during growth, overcoming the limitations of measuring total body density alone. Hence, the combination of body density and body water has become the most practical multicomponent approach to body composition assessment in growing children [10]. With the development of improved body water procedures through deuterium dilution [34, 36, 37], this approach has offered better estimates of FM and FFM in this population.

Though the use of age- and sex-specific constants improves the accuracy of 2C models in assessing FM and FFM in children, simpler field-based methods are still needed. Therefore, if the goal is to develop field-based techniques to predict body composition, multicomponent models should be used as the preferred criterion method. Therefore, the accuracy of anthropometry and BIA-based equations are dependent in part on the accuracy of the criterion variable for measuring FM and FFM but also on the statistical procedures used to develop these Type I functions.

1.3. Statistical Approach for Developing Predictive Equations. In this section, we will review the most common methods

used to developed predictive models, that is, Type I functions for assessing body composition with regression analysis, the most widely used method for their development. Briefly, predictor variables that show the highest correlation with the response variable are chosen to yield the maximum R^2 (representing the proportion of the total variance in the response variable that is explained by the predictors in a given equation) [38]. Then, a second significant variable is added to the model with the amount of shared variance increasing the R^2. The procedure is repeated to achieve the best combination of predictor variables until the inclusion of any variable no longer improves (i.e., significantly) the R^2 [38].

Another concern when developing predictive equations is multicollinearity, a condition where independent variables are strongly correlated with each other. Therefore, if too many variables are included as predictors in a given equation, the probability of multi-collinearity is increased. The variance inflation factor, defined as $1/(1 - R^2)$, can be calculated to detect multi-collinearity. To reduce the number of equations generated and the chance of multi-collinearity, the elimination of predictor variables with the lowest correlation with the reference method should be performed [38]. Additionally, to assure the appropriate number of predictors in a specific equation, Mallows' Cp statistic index [39] should be used. According to Sun and Chumlea [38], the equation with the minimum Cp will have the maximum R^2 and minimum root mean square error (RMSE) values, and as expected, a reduced bias and multi-collinearity. In the development of the regression model, the larger the R^2 the better the equation fits the data, whereas the precision of the model is evaluated by the RMSE. The RMSE is calculated as the square root of the sum of squared differences between the predicted and the observed values divided by the total number of observations minus the number of parameters [38] as follows:

$$\mathrm{RMSE} = \sqrt{\frac{\sum \left(\text{observed} - \text{predicted}\right)^2}{(n - p - 1)}}, \tag{12}$$

where n is the number of observations, and p is the number of predictor variables. The RMSE should be standardized for the mean value of the criterion method. This procedure is called the coefficient of variation (CV), a standardized value that is useful in comparing predictive equations with different response variables and different units [38].

Generally, there are specific selection criteria that should be used for testing the accuracy of new predictive Type I functions. One of the first criteria is the validity of the reference method because of its inherent error of measurement, which dose not allow for perfect criterion scores. According to Sun and Chumlea [38], other performance indicators include sample size, the ratio of sample size to the number of predictor variables, size of the coefficient of correlation (R), R^2, RMSE, and the CV for the equation [38]. To measure the increase in sample size necessary to offset the loss of precision, the ratio between the variance of prediction error and the variance of criterion value should be calculated [40]. For example, a sample of 100 participants is required to achieve a significant 1% increase in R^2 precision or accuracy of a predictive equation with a statistical power of 90% [38]. An additional procedure to assess the generalizability of predictive equations is the cross-validation of developed models. To test the performance of a predictive equation in cross-validation studies, the pure error (PE) is used. The parameter is calculated as the square root of the sum of squared differences between the observed and the predicted values divided by the number of subjects in the cross-validation sample [38] as follows:

$$\mathrm{PE} = \sqrt{\frac{\sum \left(\ddot{Y} - Y\right)^2}{n}}, \tag{13}$$

where $\ddot{Y}$ are the predicted values, Y are the observed values, and n is the number of subjects. While smaller RSME values indicate a greater precision in the development of a predictive equation, a reduced PE points to a better accuracy of the equation when applied to an independent sample. The cross-validation procedure involves the application of the developed model in another sample from the population. Usually 2/3 of the sample is used for developing a prediction equation, and 1/3 is used to cross-validate the model though other procedures can be used, such as the Jackknife method and the prediction of the sum of squares (PRESS) [41, 42]. To test the accuracy of an equation when applied to the cross-validation sample, the following parameters should be analyzed: size of the R^2, PE, and the potential for bias (mean difference between methods). Further, though less used, the concordance correlation coefficient (CCC) proposed by Lin [43], should be examined as it represents a measure of accuracy by indicating a bias correction factor that quantifies how far the best fit line deviates from the 45° line through the origin, and a measure of precision that specifies how far each observation deviates from the best-fit line. Also, for testing the performance of the newly developed equation in the cross-validation group, the agreement between methods should also be examine by analyzing the 95% limits of agreement, as proposed by Bland and Altman [44], which tests the potential for bias across the range of fatness or leanness. This is calculated by the differences of the methods (y-axis) and the mean of the methods (x-axis) (as proposed by Bland and Altman [44]). Instead, the residuals of the regression between methods with the criterion (in abscissas) have also been reported [45]. The presence of a trend between the differences and the mean of the methods is determined by using the coefficient of correlation (or instead by observing the homoscedasticity of the residuals); this is to say a significant correlation between the x- and y-axis indicates bias across the range of fatness.

1.4. Objectives. The present study aims to review all the available BIA and/or anthropometric-based equations published between 1985 and 2012 for body composition assessment developed using 3C and 4C models in the paediatric population.

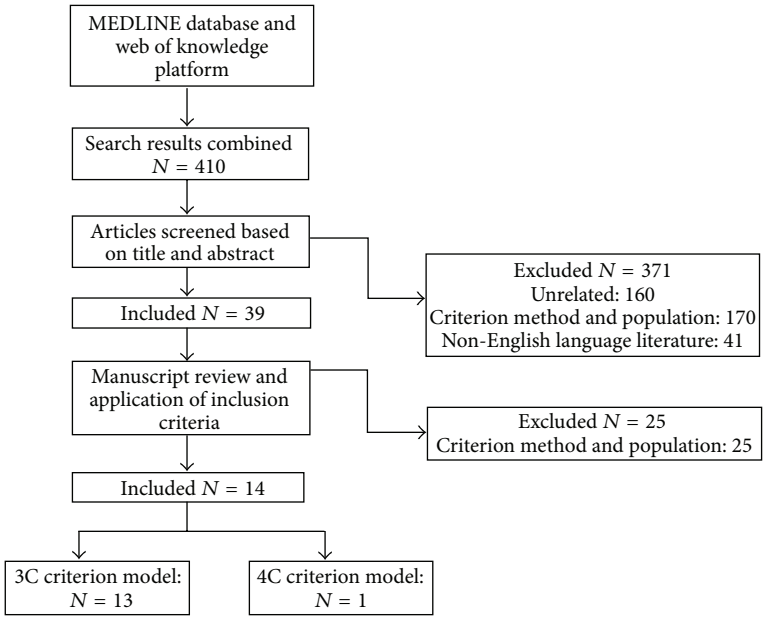

Figure 1: Flow diagram of study selection [46].

2. Methods

An extensive literature review was conducted, according to the guidelines proposed at the PRISMA statement [46], to select predictive equations for body composition estimation in a paediatric population. MEDLINE database (OVID, PubMed) and Thomson Reuters Web of Knowledge platform were searched for English language articles published in peer-reviewed journals since 1985 with the last search run on December 11, 2012. The keyword search terms included: children, adolescent, childhood, adolescence, four-compartment model, three-compartment model, multicomponent model, equation, prediction, dual-energy X-ray absorptiometry, bioelectrical impedance analysis, resistance, anthropometry, skinfold, fat, and fat-free mass. The following characteristics and criteria were used: (1) participants were healthy children and adolescents; (2) the predictor variables were based on BIA and/or anthropometry; (3) the 3C and 4C models were used as the criterion methods; (4) relative or absolute FM and FFM were assessed; (5) detailed description of the statistical methods used to formulate the equations was provided. For the identification of studies, the process included the following steps: screen of the identified records; examination of the full text of potentially relevant studies; and application of the eligibility criteria to select the included studies. For assessing eligibility, studies were screened independently in an unblinded standardized manner by the primary author, whereas the secondary author examined a small sample of them.

3. Results

Our search provided a total of 410 citations. Of these, 371 studies were discarded because after reviewing the title and abstract, it appeared that these papers clearly did not meet the criteria. The full text of the remaining 39 citations was examined in more details. A total of 25 studies did not meet the inclusion criteria described in Section 2; therefore, a total of 14 studies involving 33 equations were identified for paper. A flow diagram is illustrated in Figure 1 to describe the number of studies screened, assessed for eligibility, and included in the paper, along with reasons for exclusions at each stage.

A detailed description of the selected equations is presented in Tables 3 and 4, including the characteristics of the study sample, the response and the predictor variables, the criterion models, and the statistical methods used to validate and formulate the equations.

The studies summarized in Table 3 presented R^2 values for relative and absolute FM ranging from 0.85 to 0.93 and from 0.55 to 0.96, respectively, with RMSEs ranging from 2.60 to 3.40% for %FM and from 0.94 to 4.29 kg for absolute FM. Values of $R^2 > 0.94$ and RMSE ranging from 1.0 to 2.1 kg were found for FFM estimation. In Table 4, equations developed using a 4C model as the reference method [47] yielded R^2 that ranged from 0.76 to 0.82 with RMSE ranging from 3.6 to 3.8%. The CVs were not available for the majority of the equations. Overall, DXA was used as the reference method to estimate FM [48–53], %FM [54, 55], and FFM [56–58].

Among the 33 equations presented in Tables 3 and 4, only 7 were cross-validated [48, 52, 53, 56, 58, 59]. Only 2 studies examined the PEs [56, 58] in estimating FFM, ranging from 1.2 to 1.5 kg. During the cross-validation analysis, R^2 values ranged from 0.80 to 0.92 for absolute FM with no available information for relative FM. Cross-validation of FFM reported in one study [56] showed an R^2 value of 0.95 whereas another study provided values for the CV [58] that ranged from 5 to 6%. None of the above studies examined the CCC,

Table 3: Summary of predictive equations for children and adolescents based on a three-compartmental model.

				Development						Cross-validation								
Author	Sex	Ethnic group	Age Y	N	Criterion method	R^2	RMSE	CV (%)	Equations and predictor variables	N	Age	R^2	PE	CV	CCC	Bias	Agreement Limits	Agreement Trend
Houtkooper et al. [65]	M	Cauc	10–14	53	UWW, Deut Dilut[1]	0.85	3.3%	NA	%FM = −0.235 ∗ S, cm^2/R + 0.252 ∗ Abdcirc + 0.281 ∗ (sum: Tric, Abd, Thigh SKF) − 0.044	NA	NA	NA	NA	NA	NA	NA	NA	NA
	F			41														
Houtkooper et al. [65]	M	Cauc	10–14	53	UWW, Deut Dilut[1]	0.94	1.9 kg	NA	FFM (kg) = 0.713 ∗ S, cm^2/R + 0.15 ∗ (chest circ) + 0.493 ∗ (hip Skeletal width) + 0.121 ∗ Re − 21.41	NA	NA	NA	NA	NA	NA	NA	NA	NA
	F			41														
Houtkooper et al. [59]	M and F	Cauc	10–14	157[2]	UWW, Deut Dilut[1]	0.95	2.1 kg	5.1	FFM (kg) = 0.61 ∗ S, cm^2/R + 0.25 ∗ W + 1.31	25	10.5–14.4	0.95	NA	NA	NA	1.7	NA	NA
Goran et al. [51]	M	Cauc	4–9	49	DXA Lunar DPX-L densitometer	0.91	0.94 kg	NA	FM (kg) = 0.16 ∗ Sub SKF + 0.33 ∗ W + 0.11 ∗ Tric SKF − 0.16 ∗ S, cm^2/R− 0.43 ∗ Sex − 2.4	NA	NA	NA	NA	NA	NA	NA	NA	NA
	F			49		0.88	1.05 kg	NA	FM (kg) = 0.18 ∗ W + 0.23 ∗ Sub SKF + 0.23 ∗ Tric SKF − 3.0									
Ellis [49]	M	Cauc	3–18	145	DXA Hologic QDR 2000	0.57	3.56 kg	31.7	FM (kg) = 0.534 ∗ W− 1.59 ∗ age + 3.03	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Black		78		0.62	4.29 kg	36.1	FM (kg) = 0.594 ∗ W− 0.381 ∗ S, cm + 36.0	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Hispanic		74		0.55	3.71 kg	25.7	FM (kg) = 0.591 ∗ W− 1.82 ∗ Age + 3.36	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ellis et al. [50]	F	Cauc	3–18	141	DXA Hologic QDR 2000	0.93	1.09 kg	9.7	FM (kg) = 0.642 ∗ W − 0.12 ∗ S, cm − 0.606 ∗ Age + 8.98	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Black		104		0.96	2.44 kg	16.7	FM (kg) = 0.653 ∗ W − 0.163 ∗ S, cm − 0.298 ∗ Age + 10.7	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Hispanic		68		0.95	2.45 kg	15.1	FM (kg) = 0.677 ∗ W − 0.217 ∗ S, cm + 15.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
de Lorenzo et al. [57]	M	NA	7.7–13	20	DXA Lunar DPX densitometer	0.96	1.0 kg	NA	FFM = 2.330 + 0.588 ∗ S, cm^2/R + 0.211 ∗ W	NA	NA	NA	NA	NA	NA	NA	NA	NA
	F			15														
Dezenberg et al. [48]	M and F	Cauc and Black	4–10.9	135	DXA Lunar DPX-L	0.95	0.5 kg	NA	FM (kg) = 0.332 ∗ W + 0.263 ∗ Tric SKF + 0.76 ∗ Sex + 0.704 ∗ Ethnicity − 8.004	67	4–10.9	0.92	NA	NA	NA	−0.11	0.1–(−0.3)	0.19
Morrison et al. [58]	F	Cauc	6–17	65	Hologic QDR-1000/W	0.99	1.14 kg	3.6	FFM (kg) = 1.07 + 0.37 ∗ S, cm^2/R 0.17 ∗ Tric SKF + 0.47 ∗ W	20	9.3 ± 0.6	NA	1.5	6	NA	NA	NA	NA
		Black		61		0.99	1.95 kg	4.7	FFM (kg) = −8.78 + 0.78 ∗ S, cm^2/R + 0.10 ∗ Rc + 0.18 ∗ W	20	9.2 ± 0.5	NA	1.2	5	NA	NA	NA	NA

Table 3: Continued.

Author	Sex	Ethnic group	Age Y	Development						Cross-validation								
				N	Criterion method	R^2	RMSE	CV (%)	Equations and predictor variables	N	Age	R^2	PE	CV	CCC	Bias	Agreement Limits	Agreement Trend
Bray et al. [54]	M and F	Cauc and Black	10–12	129	DXA Hologic QDR 2000	0.91	3.1%	NA	%FM = 7.26 + 0.77 ∗ Bic SKF + 0.36 ∗ calf SKF + 0.25 ∗ Thigh SKF	NA	NA	NA	NA	NA	NA	NA	NA	NA
						0.89	3.4%	NA	%FM = 9.02 + 1.09 ∗ Bic SKF + 0.42 ∗ Calf SKF	NA	NA	NA	NA	NA	NA	NA	NA	NA
Clasey et al. [56]	M	Cauc	5–11.9	203	DXALunar DPX-IQ (GE/Lunar)	0.95	1.4 kg	NA	FFM (kg) = −7.655 + 0.297 ∗ S, cm + 0.125 ∗ W − 0.0174 ∗ Imp	38 M	5–11.9	0.95	1.2 kg	NA	NA	0.0	2.5–(−2.4)	NS
	F			158						37 F								
Flavel et al. [55]	M	Cauc	6–17	37	DXA Lunar Prodigy	0.91	3.0%	NA	%FM = 1.09 + 0.63 ∗ Tri SKF + 0.36 ∗ Thigh SKF + 0.50 Supraspinale SKF − 0.16 ∗ Abd SKF + 0.33 Bic SKF	NA	NA	NA	NA	NA	NA	NA	NA	NA
	F			33		0.93	2.60%	NA	%FM = 11.03 + 0.93 ∗ BMI + 0.30 ∗ Waist Girth − 0.24 ∗ S, cm + 0.48 ∗ Calf SKF + 0.07 ∗ Hip Girth	NA	NA	NA	NA	NA	NA	NA	NA	NA
Huang et al. [53]	M and F	Latino	7–13	64	DXA Hologic QDR 4500W	0.92	NA	NA	FM (kg) = 0.665 ∗ W− 1.606 ∗ Age − 1.882 ∗ Sex (0 = girl; 1 = boy) + 3.330	32	7–13	0.92	NA	NA	NA	0.36	6.4–(−5.7)	NS
Hoffman et al. [52]	M	Mixed ethnicity	9.8 ± 1.3	48	DXA Hologic QDR 4500A	0.78	1.2 kg	NA	FM (kg) = 6.371 + 0.488 ∗ W + 0.128 ∗ Tric SKF − 1.138 ∗ S, cm + 0.645 ∗ Sex − 0.188 ∗ Age	12	10.1 ± 1.5	0.80	NA	NA	NA	0.09	NA	NA
	F			67						18								

NA: not available; UWW: underwater weighing; DXA: dual-energy X-ray absorptiometry; Cauc: caucasians; SKF: skinfold; NS: nonsignificant; Bic SKF: bicipital skinfold; Tric SKF: tricipital skinfold; Supil SKF: Suprailiac skinfold; Sub SKF: subscapular skinfold; Abd SKF: abdominal skinfold; M: male; F: female; Deut Dilut: deuterium dilution; R^2: coefficient of determination; RMSE: root of mean square error; CV: coefficient of variation; CCC: concordance correlation coefficient; PE: pure error; BMI: body mass index; W: weight; FM: fat mass; FFM: fat-free mass; S: stature; R: resistance; Rc: reactance; Imp: impedance; abdcirc: abdominal circumference.

[1]% Fat = {(2.057/Db) − 0.786 ∗ W − 1.286} ∗ 100, where Db: body density; W: total body water [9].

[2]% Final equation was obtained from combining the development and cross-validation samples [59].

Table 4: Summary of predictive equations for children and adolescents published based on a four-compartmental model.

Author	Sex	Ethnic group	Age Y	Development						Cross-validation								
				N	Method and criterion model	R^2	RMSE	CV (%)	Equations and predictor variables	N	Age	R^2	PE	CV (%)	CCC	Bias	Agreement	
																	Limits	Trend
Slaughter et al. [47]	M	Cauc and Black	8–18*	174	UWW, Deut Dilut, SPA[1]	0.78	3.8%	NA	%FM = 0.735 ∗ (Sum: Tric and Calf SKF > 35 mm) + 1.0	NA	NA	NA	NA	NA	NA	NA	NA	NA
	F			136		0.78	3.8%	NA	%FM = 0.610 ∗ (Sum: Tric and Calf SKF > 35 mm) + 5.1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Leaner children and adolescentes (Sum: Tric + Sub SKF < 35 mm)																		
Slaughter et al. [47]	M	Cauc	Prepub	50	UWW, Deut Dilut, SPA[1]	0.80	3.6%	NA	%FM = 1.21 ∗ (Sum: Tric and Sub SKF < 35 mm) − 0.008 ∗ (Sum: Tric and Sub SKF < 35 mm)^2 − 1.7	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Black				0.80	3.6%	NA	%FM = 1.21 ∗ (Sum: Tric and Sub SKF < 35 mm) − 0.008 ∗ (Sum: Tric and Sub SKF < 35 mm)^2 − 3.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Cauc	Pub	30		0.82	3.6%	NA	%FM = 1.21 ∗ (Sum: Tric and Sub SKF < 35 mm) − 0.008 ∗ (Sum: Tric and Sub SKF < 35 mm)^2 − 3.4	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Black				0.82	3.6%	NA	%FM = 1.21 ∗ (Sum: Tric and Sub SKF < 35 mm) − 0.008 ∗ (Sum: Tric and Sub SKF < 35 mm)^2 − 5.2	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Cauc	Pospub	58 36		0.76	3.6%	NA	%FM = 1.21 ∗ (Sum: Tric and Sub SKF < 35 mm) − 0.008 ∗ (Sum: Tric and Sub SKF < 35 mm)^2 − 5.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Black				0.76	3.6%	NA	%FM = 1.21 ∗ (Sum: Tric and Sub SKF < 35 mm) − 0.008 ∗ (Sum: Tric and Sub SKF < 35 mm)^2 − 6.8	NA	NA	NA	NA	NA	NA	NA	NA	NA
	F	Cauc and Black		136	UWW, Deut Dilut, SPA[1]	0.80	3.9%	NA	%FM = 1.33 ∗ (Sum: Tric and Sub SKF < 35 mm) − 0.013 ∗ (Sum: Tric and Sub SKF < 35 mm)^2 − 2.5	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 4: Continued.

Author	Sex	Ethnic group	Age Y	Development						Cross-validation								
				N	Method and criterion model	R^2	RMSE	CV (%)	Equations and predictor variables	N	Age	R^2	PE	CV (%)	CCC	Bias	Agreement	
																	Limits	Trend
Fatter children and adolescentes (Sum: Tric + Sub SKF > 35 mm)																		
Slaughter et al. [47]	M	Cauc and Black		174	UWW, Deut Dilut, SPA[1]	0.80	3.6	NA	%FM = 0.783 ∗ (Sum: Tric and Sub SKF > 35 mm) + 1.6	NA	NA	NA	NA	NA	NA	NA	NA	NA
	F			136		0.80	3.9	NA	%FM = 0.546 ∗ (Sum: Tric and Sub SKF > 35 mm) + 9.7	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA: not available; UWW: underwater weighing; DXA: dual-energy X-ray absorptiometry; Cauc: caucasians; SKF: skinfold; Tric: tricipital; Sub: subscapular; M: male; F: female; SPA: single photon absorptiometry; Deut Dilut: deuterium dilution; R^2: coefficient of determination; RMSE: root of mean square error; CV: coefficient of variation; CCC: concordance correlation coefficient; PE: pure error; FM: fat mass; Prepub: prepubescent; Pub: pubescent; Postpub: postpubescent.

*The authors used a sample aged 8–29 years but recommended the use of the proposed models for children and adolescents aged 8–18 years.

[1]%FM = {(2.747/Db) âĂŠ (0.727 ∗ TBW/W) + (1.146 ∗ BMC/W) − 2.053 } ∗ 100, where Db body density; TBW: total body water; BMC: bone mineral content; W: body weight [66].

whereas agreement between methods was only included in 3 studies [48, 53, 56]. The smaller 95% confidence intervals for absolute FM were found for Dezenberg equations (−0.3 to 0.1 kg), while Huang equation ranged from −5.7 to 6.4 kg. For Clasey equation, FFM limits of agreement ranged from −2.4 to 2.5 kg. For all the cross-validation equations, the difference between the predictive and the reference methods showed values closed to 0, indicating a reduced bias in the cross-validation sample of the aforementioned studies.

4. Discussion

A total of 33 BIA and anthropometric-based equations for assessing body composition using multicomponent models as the reference method met the criteria and were selected and reviewed. Overall, these models provided an acceptable accuracy to be used in epidemiological studies. Generally, BIA-based equations were developed for FFM estimates, whereas anthropometric-based models were developed for FM estimates.

Several equations were developed for ages below 14 years while few published equations covered a larger broad of ages, respectively, 3 to 18 years [49, 50] and 6 to 17 y [55, 58]. The studies of Ellis et al. [49, 50] likewise presented the largest and ethnically diverse sample, including Caucasian, Hispanics, and Blacks, though the male equations only explained ~60% of the variance in the reference method.

Also, of note is the absence of including a multicollinearity analysis in the majority of the selected equations with the exception of the predictive model proposed by Morrison et al. [58]. A limited number of studies included a standardized value (CV) for the RMSEs [49, 50, 58, 59], a useful parameter for comparing predictive equations with different response variables and units.

Another important finding is the small number of studies that actually reported the cross-validation of newly proposed models [48, 52, 53, 56, 58, 59]. This is a major flaw in the ability to generalize the predictive model as it establishes whether the equation was accurate to sample-specific variations. In this regard, it is important to highlight the equation developed by Clasey et al. [56] for FFM estimation using BIA in a large sample of Caucasian children aged 5–11.9 year. The cross-validation sample used by the authors [56] comprising ~80 children explained FFM variability from the criterion method by 95%. The few studies that reported agreement between the proposed equation and the criterion method when applied to a cross-validation sample indicated that limits of agreement are relatively larger which may limit the accuracy of the models at an individual level, even though the mean bias was small. Additionally, none of the studies that included a cross-validation sample analysed the concordance correlation coefficient (CCC) proposed by Lin [43], as it represents in the same calculation a measure of accuracy and precision of the proposed methodology in relation to the reference technique.

Most of the studies presented in Table 3 were developed using DXA as the criterion method either to estimate FM [48–53], %FM [54, 55], or FFM [56–58] using different instruments, models, and scan modes. The validity of the response variable, that is, the criterion method, is determinant for developing appropriate equations based on BIA and/or anthropometry. Therefore, the usefulness of DXA as the reference method for the development of several proposed equations needs to be addressed, in particular some advantages and shortcomings of this technique to assess body composition in pediatric populations. Recently, Toombs et al. [60] pointed out that DXA technological advances demonstrated a good precision, large availability, and low radiation dose, highlighting DXA as a convenient and useful diagnostic tool for body composition assessment. These authors also concluded that DXA technology can be improved if the uncertainties associated with the trueness of DXA body composition measurements are addressed by conducting more validation studies for testing different DXA systems against *in vivo* methods such as neutron activation analysis and the 4C model [60]. Systematic variations between devices and software versions have been reported previously [61, 62]. Therefore, DXA systems are not interchangeable and generalizability of predictive equations generated by different densitometers, software, and/or scan mode is still unknown. Further research is required for addressing methodological issues related to the validity of this technique, especially if it is used as a criterion method for developing alternative solutions for body composition assessment.

It is recognized that 4C models are the best approach in pediatric populations for developing and cross-validating new body composition methods. Though other studies [63, 64] included children and adolescents in the prediction of bedside techniques using a 4C model as the criterion method, only Slaughter et al. [47] proposed solutions specifically developed for a healthy pediatric population ranging in age, maturation status, gender, ethnicity, and adiposity level. This model included bone mineral assessment from a single photon absorptiometry, and the impact of this estimation on the accuracy of those models is still unknown. Sun et al. [63] and Horlick et al. [64] also developed BIA-based equations for assessing FFM using a 4C model as the criterion method. However, we did not include these equations since a wide range of age was found for Sun et al.'s proposed models (12–94 years) [63], whereas Horlick et al. [64] included HIV-infected children along with healthy children during model development. It is important to address that multicomponent molecular models do not rely upon major assumptions regarding proportions of the FFM density or hydration which are the cornerstone of 2C models. However the use of 3C and 4C models is highly expensive, and laborious which disables its implementation in most laboratories. Though the precision of multicomponent models may be affected by the propagation of measurement error related to the need of assessing several techniques, reliability of 3C and 4C models is not compromised if technical errors are relatively small [4].

5. Conclusion

In this paper, BIA and anthropometric-based equations developed against multicomponent models for estimating

FM and FFM in children and adolescents were examined. Very few equations included a cross-validation sample, and future research efforts should include this procedure for newly proposed models to eliminate the least accurate and precise rather than to continue developing new equations.

We identified 33 prediction equations that are acceptable alternatives for epidemiological/clinical settings. The predictive equations of Slaughter, developed against a 4C model, used a wide and diverse sample ranging in age, maturation status, ethnicity, gender, and adiposity levels and should, therefore, be recommended as a feasible and valid alternative for assessing body composition in paediatric populations.

Multicomponent models, specifically the 4C model, can account for potential effects of age, sex, and ethnicity differences in the FFM density and composition when used as the criterion method nevertheless residual differences can occur. Therefore, specific BIA and/or anthropometric models for clearly defined ages, gender, and ethnic groups of children and adolescents are required using a 4C model as the criterion method.

Finally, future research studies should employ multicomponent models to accurately address the dynamic changes in paediatric body composition using, as predictors, whole body measures.

Conflict of Interests

The authors do not have any conflict of interests.

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Review Article

Measuring Body Composition in Individuals with Intellectual Disability: A Scoping Review

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Background. Research shows obesity to be more prevalent amongst individuals with intellectual disability (ID) making correct measurement of body composition crucial. This study reviewed the validity and reliability of methods used for assessing body composition in individuals with ID. *Methods*. Authors conducted electronic searches through PubMed (1990 to present) and PsycINFO (1990 to present) and assessed relevant articles independently based on scoping review guidelines. Reviewers included primary research related to the validity and reliability of body composition measures on individuals with ID. *Results*. Searches identified six articles assessing body composition methods used on individuals with ID including body mass index (BMI), skinfold thickness, bioelectrical impedance analysis (BIA), waist circumference, tibia length, and anthropometric girth measurements. BMI and waist circumference appear suitable measures but skinfold thickness measurements may not be advisable due to participants' noncompliance resulting in a lack of precision and inaccurate results. *Conclusions*. The current literature contains too few well-conducted studies to determine the precision and validity of body composition measures on individuals with ID. There may be a need to devise further regression equations that apply to individuals with specific types of ID in order to increase the reliability and validity of body composition measurements.

1. Introduction

Individuals with intellectual disability (ID) are at increased risk for obesity and extreme obesity [1], which contribute to numerous cardiovascular, pulmonary, and metabolic diseases [2, 3]. More specifically, research documents physiological mechanisms that associate total and regional body fat with insulin resistance, glucose metabolism, serum lipid concentrations, and blood pressure [4].

Recommended by the World Health Organization [5], body mass index (BMI) and waist circumference are used frequently to measure obesity across different populations. Yet, there remains a question as to the extent these methods accurately reflect body composition or fat distribution in individuals with ID who often display unique anthropometry compared to individuals without disabilities [6].

Several alternative solutions are available to scientists and practitioners seeking to assess obesity in individuals with different types of ID. Laboratory or "reference" methods, such as air displacement plethysmography (ADP), hydrostatic weighing, and dual-energy X-ray absorptiometry (DXA), are conducted often with reliable results on diverse populations [7] even if their expense and lack of portability sometimes limit their use in community-based settings. Field methods including skinfold thickness and bioelectrical impedance analysis (BIA) also offer practical and more cost-effective alternatives but, unlike the high-precision laboratory methods, the accuracy of these methods remains dependent largely upon specific regression equations that should be selected on the basis of a participant's age, gender, ethnicity as well as physical activity, and body fat levels. Research demonstrates that such equations should be limited only to the type of population in which they have been validated otherwise there is an increased risk that they may underestimate or overestimate body fat levels [8–11].

It is essential to know which body composition methods are accurate and feasible for determining health status in individuals with ID. However, no study to our knowledge has reviewed measures used on this population despite the growing efforts being made to combat obesity through health

promotion initiatives [12]. Therefore, the purpose of this study is to review the reliability and validity of methods used for assessing body composition in individuals with ID.

2. Aim and Methods of Review

Researchers carried out a scoping review relating to the validity and reliability of body composition measures in individuals with ID. A scoping review offers a primary evaluation of the range of the available literature on a particular topic [13] and is especially pertinent in disability and health research where there remains a lack of uniformity in the study design and measurement. The author followed the framework of Arksey and O'Malley [14] who underscored five key phases when conducting a scoping review: (i) identifying the research question; (ii) identifying relevant studies; (iii) study selection; (iv) charting the data; and (v) collating, summarizing, and reporting the results.

The scoping review addressed the following questions. (1) What measurement tools have researchers used when assessing body composition in individuals with ID? (2) What are the validity and/or reliability of these methods according to the empirical literature? In order to address these questions,researchers sourced journal articles from PubMED (1990–2012) and PsycINFO (1990–2012) and retrieved articles using the keywords "intellectual disability" and "mental retardation" in conjunction with "body composition," "body fat," "anthropometry," and "obesity". Reviewers excluded review articles but examined their reference lists to highlight relevant articles. Reviewers included primary research related to the validity and reliability of body composition measures on individuals with ID. For validation purposes, the following measures are included: coefficient of determination (r^2); coefficient of correlation (r); root mean square error (RMSE) or standard error of estimation (SEE); bias (mean difference between the alternative and the criterion method), and the agreement (usually assessed by the Bland-Altman method) represented by the upper and lower of the 95% confidence intervals of the bias (mean difference ±2 standard deviations). The following parameters are used for assessing reliability: intraclass coefficient of correlation (ICC, also reported for validation purposes); Cohen's kappa; coefficient of variation (CV); and technical error of measurement (TEM). For inclusion, studies had to (i) feature a population with any kind of ID [15]; (ii) assess body composition; and (iii) evaluate the validity and/or reliability of body composition measures. No study was excluded based on the methodology but the scope was limited to studies written in English and published in peer-reviewed journals between 1990 and 2012.

The main author, along with a peer, screened titles, abstracts, and results for inclusion independently. When disagreement occurred concerning inclusion, researchers reevaluated articles and came to an agreement following arbitration. Figure 1 illustrates the article selection process.

3. Results

The searches extracted 1940 peer-reviewed articles from both electronic databases. Researchers removed any duplicates leaving 1932 journal citations. Six studies adhered to the inclusion criteria producing a small but heterogeneous range of samples and methodologies [16–21]. The results showed that four studies (67%) included participants with various levels of ID [16–19] with the two remaining studies (33%) featuring participants only with Down syndrome (DS) [20, 21]. Temple et al.'s [17] research included individuals with DS and Duane syndrome under the generic term ID. Two additional studies included participants only with severe disabilities [16, 19] while another contained a comparison group without disabilities [21]. Table 1 provides a summary of all studies included under the criteria laid out in the method section and documents author information, key research questions, subjects, design, and measurement tools as well as outcomes.

Four of the studies that met our inclusion criteria attempted to cross validate anthropometric measurements using a criterion measure, namely, ADP [20, 21], DXA [17], and isotope dilution [16]. The validity of skinfold thickness generalized prediction equations was tested in four studies (67%). The prediction equations featured in the included studies were those of Jackson & Pollock [22], Kelly et al. [23], Lohman [24], Jackson et al. [25], Durnin & Womersley [26], Gurka et al. [27], Pencharz & Azcue [28], Slaughter et al. [29], Johnston et al. [30], and Brook [31]. Studies focusing on individuals with DS [20, 21] and severe neurological impairment [16] suggest that further work is needed to validate prediction equations for these specific populations. Results also indicated that skinfold measures may produce high levels of noncompliance amongst different populations with ID [16, 18, 19]. Criterion measures ADP and DXA reported high levels of compliance in individuals with DS [20, 21] and ID [17], respectively.

The feasibility of anthropometric girth measurements (AGM), BMI [17–19], waist circumference [18, 19], tibia length [19], and BIA [16, 18] as measures of body composition were also examined by various researchers in diverse populations with ID. BIA [16, 18] and BMI [17–19] were found to be practical measures for different populations with ID but no such data was available for individuals with DS.

4. Discussion

The purpose of this study was to review the validity and reliability of methods used to measure body composition in individuals with ID. Only six studies met the inclusion criteria so it remains difficult to draw definitive conclusions based on such limited data but findings thus far indicate that BMI [17], waist circumference [21], and tibia length measurements [19] may be used reliably on individuals with ID. However, results throw into question the use of skinfold thickness and non population-specific equations on populations with ID including DS [16, 18, 20, 21].

It is disconcerting that few studies have made valid and reliable measures for assessing body composition amongst individuals with ID especially when one considers elevated levels of obesity and an increasing number of physical activity- and nutrition-based interventions that focus on

Table 1: Reliability and validity of body composition measurements in individuals with intellectual disabilities.

Author(s)	Subjects mean (SD)	Measure	Regression equation	Reference method	Results: reliability and validity	Summary
Usera et al. (2005) [21]	14 adults with DS; 38(11) yrs.	SKF AGM	SKF: Jackson and Pollock [22]. AGM: Kelly et al. [23]; Lohman [24]	ADP with BOD POD	Validity: correlations with reference method and RMSE: Jackson et al. (r = .54), RMSE = 14.90; Lohman (r = .43), RMSE = 13.20; Kelly and Rimmer (r = .11), RMSE = 9.82.	Lack of validity in 3-field-based methods. New equations for DS recommended
Verstraelen et al. (2009) [18]	76 adults with ID; 19–72 yrs.	BMI WC BIA SKF	Jackson et al. [25]; Durnin and Womersley [26]	—	Reliability: *Cohen's* kappa with 90% CI. Intertest agreement among BMI & WC (0.61). Agreements between BMI SKF & FFM index, WC to SKF & FFM and SKF to FFM (<0.6)	BIA & WC feasible measures. Lack of reliability and large noncompliance for both SKF (n = 5) and FFMI (BIA) (n = 14).
Waninge et al. (2009) [19]	45 severe ID; 38(11) yrs.	BMI WC SKF Tibia length		—	Reliability: ICC for all variables (95% CI) except SKF (>0.90).	Measuring tibia length possible. Noncompliance and low reliability noted for all SKF measurements
Temple et al. (2010) [17]	46 adults mild to mod ID; 19–60 yrs.	BMI	—	DXA	Validity: BMI accounted for 68% of variance in %BF (r^2). Partial correlation of BMI with fat (r = 0.91) and fat-free mass (r = .12)	BMI reasonable indicator of adiposity.
Rieken et al. (2011) [16]	61 children w/neurol. disability and severe ID; 10(4) yrs.	SKF BIA Tibia length	SKF: Gurka et al.[27]; Rieken et al. [16] BIA: Pencharz and Azcue [28]; Rieken et al. [16]	Isotope dilution	Validity: ICC SKF-Gurka et al. [27] mean Difference = −9.2 ± 16.7; ICC = 0.51; SEE = 5.1 kg; R^2 = 0.27; Rieken et al. ICC = 0.59; SEE = 7.6 kg; R^2 =0.44; SEE = 2.2 kg; R^2 = 0.88; BIA- Pencharz and Azcue [28] Mean difference = 2.6 ± 4.4; ICC = 0.94; Rieken et al. ICC = 0.96; SEE 1.7 kg; R^2 = 0.92	SKF met with noncompliance (n = 12). Low reliability and validity for SKF compared to BIA.
Gonzalez-Aguero et al. (2011) [20]	28 children with DS; 10–20 yrs.	SKF	Slaughter et al. [29]; Durnin and Womersley [26]; Johnston et al. [30]; Brook [31]	ADP	Validity: Slaughter et al. [29] (r = 0.105 (P = 0.583)); mean difference = 0.69; 95% CI = 25.8; Durnin and Womersley [26] (r = 0.529 (P < 0.05)); mean difference = 2.34; 95% CI = 18.0; Johnston et al. [30] (r = 0.665 (P < 0.05)); mean difference = 2.73; 95% CI = 19.6; Brook (r = 0.389 (P < 0.05)); mean difference = −2.45; 95% CI = 22.3	Slaughter's equation most accurate despite wide LOA. Other equations displayed substantial intermethods difference and under- or overestimation of % BF.

ID: intellectual disability; DS: Down syndrome; AGM: anthropometric girth measurements; SKF: skinfold; BIA: bioelectrical impedance analysis, ADP: air displacement plethysmography; WC: waist circumference; FFMI (BIA): fat-free mass index derived by bioelectrical impedance analysis; %BF: percent body fat; ICC: intraclass correlation coefficients; CI: confidence interval; r: coefficient of correlation; LOA: limits of agreement.

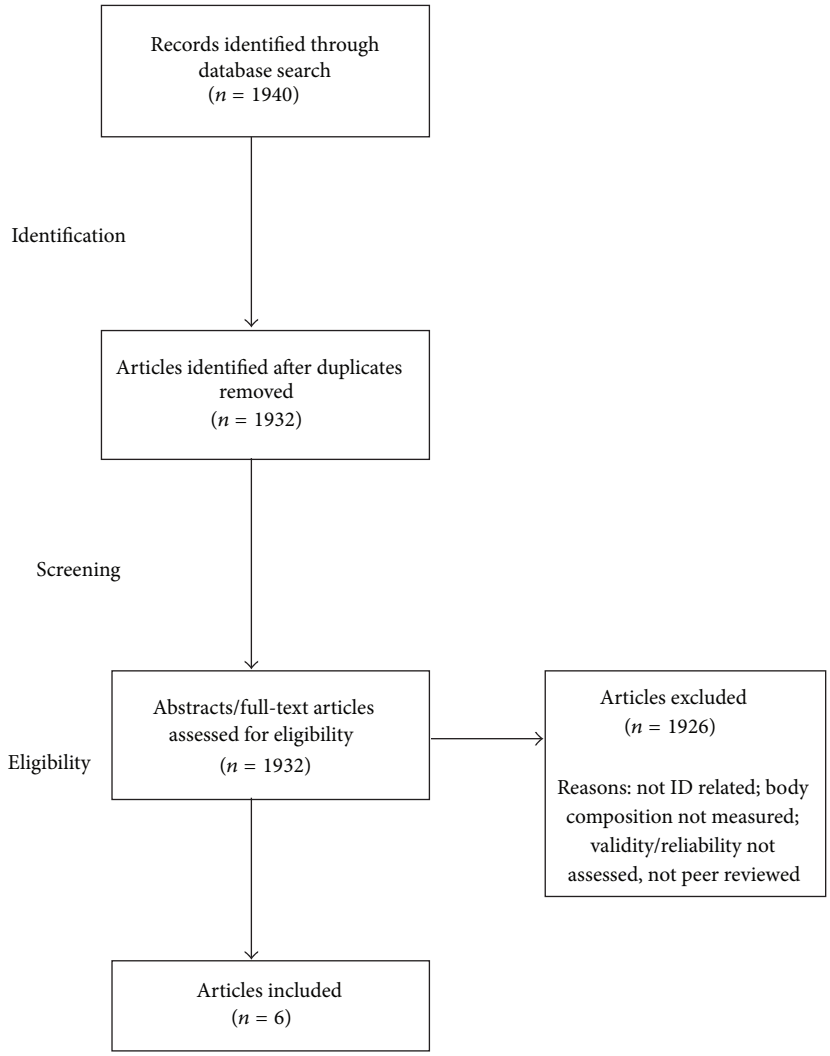

Figure 1: Scoping review of the literature on body composition measures for individuals with intellectual disability.

this population. Included studies contained heterogeneous samples despite the existence of large differences in body composition and fat distribution between participants with different types of disabilities. Only two studies concentrated solely on individuals with DS [20, 21] and, unlike for the general population, no study was gender- or race-specific. Moreover, three studies included samples of participants, which might have included many different subtypes of ID and developmental disabilities such as DS, Duane syndrome, and autism spectrum disorders. Future research may need to ponder further the physiological differences associated with each specific disability.

Two studies indicate that BMI may be a feasible method for assessing body composition in individuals with ID [17, 18]. BMI showed good agreement with DXA and provides a relatively straightforward means of gauging body composition. However, BMI should still be used cautiously as it takes body fat and fat-free mass as one value [32] while Temple et al. [17] also observed that the measure may misclassify some individuals who are obese but these results should be interpreted cautiously as the sample included 17 participants with DS whose fat distribution may be more truncal compared to other disabilities [20]. Waist circumference measurement was found to be feasible in two reports [18, 19], but overall the sensitivity in identifying obesity-related risk factors may vary based on specific populations with ID [33].

One of the main findings of this review was that preexisting prediction equations used on people without disabilities may not be suitable for individuals with ID who possess unique body proportions and characteristics [15–21]. Only two equations were recommended for people with ID across the six studies [28, 29]. Gonzalez-Aguero et al. [20] found that the equation of Slaughter et al. [29] may be acceptable for individuals with DS despite the large limits of agreement. Rieken et al. [16], examining a sample with severe neurological impairment and ID, devised a new BIA-based prediction equation and found it to be more accurate at assessing health status in this specific population than

preexisting measures of skinfold thickness. Gonzalez-Aguero et al. [20] found that three additional equations under- or overestimated body fat compared to the reference method ADP [26, 30, 31] while Usera et al. [21] discovered that three prediction equations lacked validity when assessing body composition among young people with DS [22–24]. These findings are disconcerting as many researchers have used the above equations to judge the effectiveness of their health promotion interventions on participants with ID [12].

Until more population-specific equations are introduced, it may be advisable for researchers and practitioners to bypass field measures such as BIA and skinfold in favour of more complex and precise tools [12]. Hydrostatic weighing is used frequently on the general population but may be difficult for individuals with ID as it requires complete submersion underwater; therefore, participant compliance may be difficult to achieve [34]. Usera et al. [21] found ADP to be a convenient alternative for individuals with and without DS and this method has previously shown high reliability and validity in adults when compared to hydrostatic weighing [35]. It is important to state that hydrostatic weighing and ADP are densitometric techniques and therefore, fat mass calculation using these techniques is obtained by assuming that fat-free mass density is relatively stable (at 1.1 kg/L), a cornerstone constant when using a two-compartment model. Temple et al. [17] chose DXA as a reference method and DXA scans have been applied frequently to examine children and adolescents without ID in both clinical and research settings [9, 36]. DXA's potential benefits include its quick scan time and its accurate measurements in diverse populations. DXA displays minimal bias based on age, sex, physical activity level, race, or proportion of body fat [37, 38] and remains relatively straightforward to operate without the need for active participant involvement, which is an important consideration when working with individuals with ID who may not always comply with more invasive measures. DXA can be considered a three-compartment model, thus reducing the variability of assuming a constant fat-free mass composition of two-compartment models. Still, the use of a four-compartment model for developing and/or validating equations for people with ID is absent and is required. The four-compartment models are the state-of-the art methods for assessing fat mass as no assumptions are needed with respect to fat-free mass composition and density which is important in ID individuals as these components can vary significantly from the healthy adult, specifically total body water and mineral.

Study Limitations. Several limitations should be considered when interpreting results of this scoping review. The limited number of studies meeting our inclusion criteria often featured small and heterogeneous samples along with quasi-experimental designs, so it may be difficult to generalize results to larger populations with ID. This scoping review represented a preliminary assessment of the potential size and scope of the available research literature in this area and did not include a formal quality assessment. Nonetheless, this review may lay the groundwork for a systematic review in the future and has uncovered several important findings that may require greater attention.

5. Conclusions

Limited research has assessed the validity and reliability of body composition measures for individuals with ID. The current literature contains too few well-conducted studies to evaluate the effectiveness of body composition measures on this population. BMI and waist circumference do remain practical options for professionals working with individuals who have ID. Yet, our review has also revealed that current prediction equations, used with skinfold thickness measurements and BIA, have either underestimated or overestimated body fat when compared to reference methods. Skinfold measurement has also caused compliance difficulties among participants, which calls into question its usefulness in evaluating the body composition. Future research with larger and more homogeneous samples may well be needed in order to uncover alternative methods that provide accurate measurements for such unique populations. There is also a need to place greater emphasis on finding population-specific prediction equations that are suitable for individuals with ID.

Conflict of Interests

The author declares no conflict of interests.

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Research Article

Anthropometric Changes in the Brazilian Cohort of Older Adults: SABE Survey (Health, Well-Being, and Aging)

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The aim of the present study was to analyze the anthropometric changes in a home-based cohort of Brazilian older adults who participated in the SABE Survey, conducted in 2000 and 2006. A total of 1030 men and women were examined by age group: 60–69, 70–79, and ≥80 years. This representative sample consists of the survivors of the 2000 cohort. The following anthropometric variables were assessed: body mass, arm muscle, waist and calf circumferences, triceps skinfold thickness, body mass index, waist-hip ratio, and arm muscle area according to mean values and percentile distribution. Except for body mass and body mass index, a significant difference ($P < 0.05$) was observed among the assessed anthropometric variables during the follow-up period. The older adults ≥80 years presented the lowest values. The reduction in the mean values of triceps skinfold thickness was greater (30%) than that of waist circumference (9%) and was more pronounced in women (21%) than in men (9%). Arm muscle circumference and area reduced by 8% and 19%, respectively, in men and 1% and 3%, correspondingly, in women. Our findings revealed reductions in the mean values for all anthropometric variables in the follow-up period from 2000 to 2006 among older adults.

1. Introduction

The population aging and its socioeconomic and biopsychosocial implications are a widely discussed topic globally, including in Brazil, because this group is more vulnerable to the development of noncommunicable diseases such as diabetes mellitus, hypertension, dyslipidemia, cardiovascular disease, and cancer. These diseases, associated with changes of the aging process, can compromise individual health and affect nutritional status [1]. For these reasons, this issue arouses the interest of researchers, as additional knowledge about the aging process and its impact on the Brazilian health system is required [2].

The aging process is associated with significant changes in body composition, including quantitative and qualitative progressive loss of skeletal muscle mass and body fat redistribution, with greater accumulation in the intra-abdominal region compared to the subcutaneous abdominal area, independent of disease development [3, 4]. The redistribution of adipose tissue mass and the relative decline of skeletal muscle mass can occur even when there are no significant changes in body mass index (BMI) [5]. Several longitudinal studies suggest that fat mass increases with age in older men, but not in older women, and that lean mass decreases with age in both genders; however, there is still controversy in the scientific literature on this subject [3, 5].

For understanding the body composition changes in community-dwelling older adults, longitudinal studies are needed [5, 6]. In Brazil, studies of this nature are scarce. SABE Survey aimed to verify the changes that occurred in the process of getting old and the life and health conditions of older adults in Brazil [7]. The objective of this study was to analyze the anthropometric changes, by gender and age group, in Brazilian older adults.

2. Methods

2.1. Participants and Study Protocol. The data came from the SABE Survey (Health, Well-being, and Aging), which is a longitudinal study that began in 2000, involving a probabilistic sample of older adults (≥60 y), both genders, home-based, in the city of São Paulo (n = 2, 143), Brazil [8, 9]. In 2006, the study was conducted with 1,115 participants from baseline that were interviewed again [7].

Sampling procedures in SABE study have been reported elsewhere. Briefly, the individuals were selected at random from the population count conducted in Brazil, in 1996, by the Brazilian Institute of Geography and Statistics (IBGE). The sampling process was conducted in two stages: the first, a probabilistic sample of 1,568 individuals, and the second, a further 575 individuals, to compensate the higher rate of male mortality and lower population density of the group ≥75 y, resulting in 2000, in a sample of 2,143 individuals [8].

The data collection was done by trained interviewers, using a specific questionnaire proposed by the Pan American Health Organization (PAHO), translated and adapted for use in Brazil. Each questionnaire was reviewed by a specialized technical group [8].

During the followup (2000 to 2006), there was a reduction in the number of participants from 2,143 to 1,115 [7]. The final sample for this study consisted of 1,030 subjects (92.4% of the original 1,115), as shown in Figure 1. For this study, the inclusion criterion was the existence of all anthropometric data for the description and proposed analysis.

The SABE Survey was approved by the Ethics in Research Committee of the Faculty of Public Health of the University of São Paulo and National Committee for Ethics in Research (CONEP) and all participants gave written consent before participation.

2.2. Measurements. The following anthropometric variables were assessed: body mass (BM), arm circumference (AC), waist circumference (WC), calf circumference (CC), triceps skinfold thickness (TSF), body mass index (BMI), arm muscle circumference (AMC), arm muscle area (AMA), and waist-hip ratio (WHR), by gender and age group (60–79, 70–79, and ≥80 y). BM represents the total body mass; AC is predictive of AMC and AMA; TSF is used as an indicator of the body fatness; WC and WHR represented the visceral fat, an important metabolic risk factor; AMC and AMA are indicators of the skeletal muscle mass; and BMI indicates the nutritional status.

The measurement techniques adopted were those given by Frisancho [10], the collection was in triplicate, and the mean values of these data for BM, AC, WC, CC, and TSF were used for the analysis. In both periods a total of six SABE Survey certified technicians performed the anthropometric measurements according to SABE standardized protocol. All the previous measurements were undertaken on individuals capable of walking; however, bedridden subjects had only their AC, CC, and TSF measured.

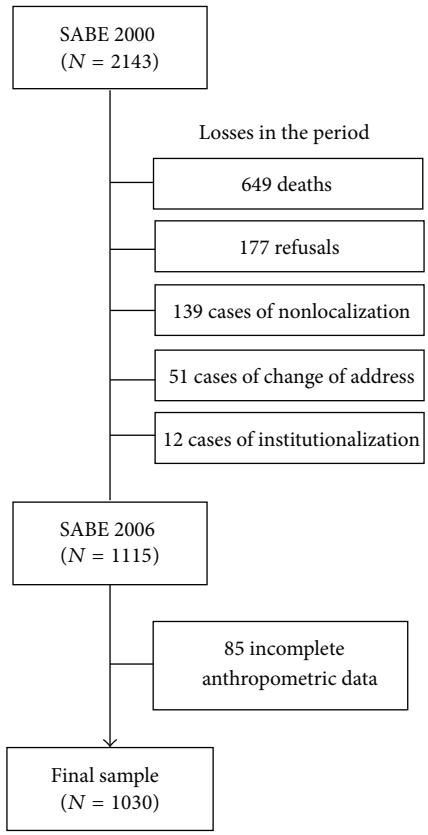

Figure 1: Final sample of older adults according to changes that occurred in the period, SABE Survey, 2000–2006.

Body mass was measured on portable scales (Seca, Germany), with capacity of 150 kg and sensitivity of 0.1 kg; height (H), with an anthropometer (Harpenden, England), with maximum height of 2.0 m; arm, calf, and waist circumferences, with an inelastic tape (1.5 m in length); and the triceps skinfold thickness with a Lange caliper, at a constant pressure of 10 g/mm^2, capacity of 67 mm graduated in mm. BMI was calculated as the ratio between the values of body mass (kg) and squared height (m) (BM/H^2) and WHR as the ratio of waist circumference (cm) to hip circumference (cm), whereas the arm muscle circumference and the arm muscle area were calculated using the following equations:

(i) Gurney and Jelliffe, 1973 [11]:

$$\text{AMC (cm)} = [\text{AC (cm)} - (\pi * \times \text{TSF (cm)})], \quad (1)$$

(ii) Heymsfield et al. (1982) [12], by gender:

men:

$$\text{AMA}\left(\text{cm}^2\right) = \frac{\{\text{AC (cm)} - [\pi * (\text{TSF (cm)} \div 10)]\}^2}{4\pi} - 10\,\text{cm}^2, \quad (2)$$

women:

$$\text{AMA}\left(\text{cm}^2\right) = \frac{\{\text{AC (cm)} - [\pi * (\text{TSF (cm)} \div 10)]\}^2}{4\pi} - 6.5\,\text{cm}^2, \quad (3)$$

where AC is arm circumference, TSF is triceps skinfold thickness, and $\pi = 3.1416$.

2.3. Statistical Analysis. Considering the type of study (survey-type [svy] command) and the complexity of the sample, statistical analysis was performed. The relative frequency corresponds to the weighted frequency in accordance with the weight of the sample of the Brazilian census office. To analyze the anthropometric changes, by gender and age group, which occurred from 2000 to 2006, a confidence interval (CI) of 95%, significance level <5%, and the Wald test were adopted. Additionally, the relative variations (%) in the follow-up years, between age groups, gender, and year were observed. Means and standard deviations were expressed in percentiles (P5, P10, P15, P25, P50, P75, P90, and P95) and the Stata/SE 10.0 for Windows program was used for the calculations.

3. Results

The mean anthropometric values presented a reduction with advancing age in both genders and age groups. Regarding mean values of calf and waist circumference, waist-hip ratio, and triceps skinfold thickness, a significant difference was only observed for women ($P < 0.05$) whereas for arm muscle circumferences and arm muscle area, differences were found between genders.

As regards BM, a significant decrease in the mean values was observed by genders and age group. The loss of weight was more pronounced in the group ≥80 years, in both women (1.5%, 4.0%, and 6.4%) and men (2.0%, 2.2%, and 4.7%) (Tables 1 and 2).

Regarding BMI, the decrease was similar in both genders, with significant statistical difference between the age groups 60 to 69 and 70 to 79 years. The women had the highest mean BMI values (Tables 3 and 4).

Concerning arm and calf circumferences, the reduction was significantly greater in women (7% and 5%, resp.) than in men (5% and 4%, resp.) (Tables 1 and 2). The mean values of AMC and AMA tend to reduce more in men (8% and 19%) than women (1% and 3%) in all age groups but significant differences were only found for the group ≥80 y (Tables 3 and 4).

The reduction of the mean values of TSF, WC, and WHR was greater in women (21%, 7% and 4%, resp.) than men (9%, 3% and 1%, resp.), being more pronounced in the age group ≥80 years, with significant difference in females in the follow-up period (Tables 1, 2, 3, and 4).

4. Discussion

This is the first epidemiological, home-based, cohort study conducted on a representative sample of Brazilian aged people (≥60 y) to report changes in mean anthropometric values and percentile distribution, by gender and age group.

With the process of aging, physical changes occur with a decrease of tissue-level components (subcutaneous adipose tissue mass, skeletal muscle mass, and bone tissue mass) [13], as supported by several investigators using whole-body level measurements [14–20] and observed in this study.

As expected, in all age groups, the mean values of BM were lower among women. The reduction of the mean values of BM was seen to accompany advancing age in both genders, being more pronounced between older old adults (≥80 y, in 2000, and ≥86 y, in 2006). These results are similar to those of other cohort studies of older adults [14–19]. Body mass change with advancing age is associated with a change in body composition that occurs with aging, especially in fat-free mass [21]. The mean BM value (65 kg) was observed to be greater in Brazilian aged people than in Chinese ≥ 70 years [14], but lower than that of Europeans ≥ 65 years [15–18] and Americans ≥ 75 years [19].

Although the loss of weight is common in the older adults, especially in the oldest of the old, care is necessary in the interpretation of this progressive loss of body weight which may result in undernutrition being often ignored by health professionals [22]. Studies show that older adults malnourished are at greater risk of developing complications and diseases and that the likelihood of hospitalization and death is increased [22, 23].

The mean values of the BMI also presented a reduction, in both genders and all age groups, with advancing age, as noted in other cohort studies [14–17]. They are greater in Brazilian older adults than in those of the other Latin American countries which participated in the SABE Survey, namely, Mexico [24], Chile [25], and Cuba [26], but lower than in those of the United States [27] and Italy [15].

Low values of BMI are related to respiratory and infectious diseases, cancer, depression, worsening of chronic diseases, changes in functional capacity, prolonged recovery from illness, and a higher number of hospitalizations, all associated with increased susceptibility to morbidity and lower survival rates [28]. Some authors have suggested higher values of BMI as reference for the older adults so that they may better face up their health problems [29, 30].

A reduction of the anthropometric parameters representing skeletal muscle mass was more pronounced in men, as occurred in other studies [14–20], and can lead to decreased strength and physical capacity [31, 32], characterizing the worst prognosis. Various factors have been described in the literature as explaining the change in total skeletal muscle mass in the older adults, including physical inactivity, changes

Table 1: Percentile distribution of anthropometric values of women by age group (SABE Survey, São Paulo, Brazil, 2000–2006).

Age groups (years)	N	X	SD	Percentiles						
				5	10	25	50	75	90	95
BM(kg)[§]										
2000[†]										
60–69	290	65.3[a]	11.6	48.5	51.0	57.0	64.0	72.0	80.0	86.0
70–79	244	63.9[a]	13.6	44.0	46.5	54.0	62.5	73.5	81.5	88.0
≥80	78	59.3[b]	12.3	37.0	43.0	50.0	60.0	67.0	74.0	80.5
2006[†]										
66–75	290	64.3[a]	12.2	46.0	50.0	56.0	63.0	71.5	81.0	87.0
76–85	244	61.3[b]	14.0	42.0	45.0	50.0	60.0	71.0	81.0	87.0
≥86	78	55.5[c]	11.5	36.0	42.0	48.0	55.0	63.0	72.0	76.0
H (m)[§]										
2000[†]										
60–69	291	1.52[a]	0.06	1.42	1.44	1.48	1.53	1.57	1.61	1.64
70–79	243	1.51[b]	0.06	1.41	1.43	1.47	1.52	1.56	1.59	1.62
≥80	75	1.49[b]	0.07	1.38	1.38	1.45	1.50	1.55	1.59	1.62
2006[†]										
66–75	291	1.52[a]	0.06	1.42	1.44	1.48	1.53	1.57	1.61	1.64
76–85	243	1.51[a]	0.06	1.42	1.43	1.47	1.51	1.56	1.61	1.62
≥86	75	1.49[b]	0.06	1.37	1.39	1.44	1.50	1.53	1.57	1.61
AC (cm)										
2000[#]										
60–69[§]	294	32.1[a]	3.61	27.0	28.0	29.0	32.0	35.0	36.0	38.0
70–79[§]	262	31.4[a]	4.69	24.0	26.0	29.0	31.0	34.0	37.0	40.0
≥80	95	29.0[b]	3.96	22.0	23.0	27.0	29.0	32.0	34.0	35.0
2006[†#]										
66–75	294	30.1[a]	3.92	25.0	26.0	28.0	30.0	33.0	36.0	38.0
76–85[§]	262	29.4[b]	4.72	23.0	24.0	26.0	29.0	32.0	36.0	38.0
≥86	95	26.3[c]	3.74	20.0	21.0	24.0	27.0	29.0	31.0	31.0
TSF (mm)[§]										
2000[†#]										
60–69	294	28.3[a]	7.04	18.0	20.0	23.0	28.0	33.0	37.0	40.0
70–79	260	27.3[a]	9.41	12.0	14.0	21.0	27.0	34.0	40.0	42.0
≥80	93	22.3[b]	7.67	10.0	11.0	17.0	23.0	27.0	31.0	34.0
2006[†#]										
66–75	294	22.6[a]	5.73	14.0	16.0	19.0	22.0	26.0	30.0	32.0
76–85	260	20.9[b]	6.69	11.0	12.0	16.0	20.0	25.0	30.0	33.0
≥86	93	17.8[c]	5.14	10.0	10.0	15.0	18.0	22.0	24.0	25.0
CC (cm)										
2000[†#]										
60–69	293	36.6[a]	3.7	31.0	32.0	34.0	36.0	39.0	41.0	43.0
70–79	261	35.7[b]	4.0	29.0	30.0	33.0	36.0	39.0	41.0	42.0
≥80	94	33.9[c]	3.2	28.0	30.0	31.0	34.0	36.0	38.0	39.0
2006[†#]										
66–75	293	35.5[a]	3.8	30.0	31.0	33.0	35.0	38.0	40.0	42.0
76–85	261	34.1[b]	4.4	27.0	29.0	32.0	34.0	37.0	39.0	41.0
≥86	94	31.8[c]	3.9	25.0	26.0	29.0	32.0	34.0	36.0	38.0

BM: body mass; H: height; AC: arm circumference; TSF: triceps skinfold thickness; CC: calf circumference; X: mean values; SD: standard deviation.

[†]Statistical differences among age groups, $P < 0.05$ (equal superscript letters: no statistical differences between age groups; different superscript letters: statistical differences between age groups).

[§]Statistical differences between genders.

[#]Statistical differences between 2000 and 2006.

Table 2: Percentile distribution of anthropometric values of men by age group (SABE Survey, São Paulo, Brazil, 2000–2006).

Age groups (years)	N	X	SD	Percentiles						
				5	10	25	50	75	90	95
BM (kg)[§]										
2000[†]										
60–69	157	71.2[a]	11.9	55.5	57.5	63.0	70.7	79.0	86.2	89.0
70–79	148	68.0[b]	11.4	49.0	53.2	62.0	67.0	74.0	80.5	91.0
≥80	61	66.2[b]	11.4	48.0	52.0	59.0	66.0	75.0	81.0	85.0
2006[†]										
66–75	157	69.8[a]	12.0	53.0	55.0	61.0	68.5	78.0	85.0	90.0
76–85	148	66.5[b]	11.6	45.0	51.0	60.0	66.0	73.0	81.5	87.0
≥86	61	63.1[b]	11.0	46.0	49.0	55.0	62.0	71.0	79.0	81.0
H (m)[§]										
2000										
60–69	157	1.65	0.06	1.55	1.58	1.61	1.65	1.70	1.74	1.77
70–79	147	1.63	0.07	1.51	1.55	1.60	1.63	1.69	1.73	1.76
≥80	58	1.63	0.06	1.52	1.56	1.59	1.64	1.67	1.70	1.75
2006										
66–75	157	1.65	0.06	1.55	1.58	1.61	1.66	1.70	1.74	1.76
76–85	147	1.63	0.07	1.52	1.54	1.59	1.63	1.68	1.74	1.77
≥86	58	1.63	0.07	1.53	1.55	1.60	1.64	1.68	1.72	1.74
AC (cm)										
2000[†#]										
60–69[§]	159	30.8[a]	3.1	27.0	28.0	29.0	30.0	32.0	35.0	36.0
70–79[§]	155	29.6[b]	3.2	25.0	26.0	28.0	30.0	32.0	33.0	35.0
≥80	65	28.8[b]	2.9	24.0	26.0	27.0	29.0	30.0	33.0	34.0
2006[†#]										
66–75	159	29.7[a]	3.1	25.0	26.0	28.0	29.0	31.0	34.0	35.0
76–85[§]	155	28.1[b]	3.2	23.0	24.0	26.0	28.0	30.0	32.0	34.0
≥86	65	26.7[c]	2.9	22.0	23.0	25.0	26.0	29.0	30.0	32.0
TSF (mm)[§]										
2000										
60–69	159	17.1[a]	7.1	7.0	8.0	10.0	14.0	21.0	26.0	30.0
70–79	155	16.5[ab]	7.2	6.0	7.0	10.0	13.0	18.0	21.0	29.0
≥80	65	15.3[b]	5.1	8.0	8.0	11.0	15.0	17.0	19.0	23.0
2006[†]										
66–75	159	15.8	5.4	9.0	10.0	14.0	17.0	20.0	23.0	27.0
76–85	155	14.4	5.5	8.0	9.0	13.0	16.0	20.0	24.0	26.0
≥86	65	14.2	5.0	6.0	9.0	12.0	15.0	19.0	22.0	23.0
CC (cm)										
2000[†]										
60–69	159	36.5[a]	3.8	32.0	33.0	34.0	36.0	38.0	40.0	43.0
70–79	155	35.6[b]	3.1	31.0	31.0	34.0	35.0	38.0	39.0	40.0
≥80	68	34.7[b]	3.3	29.0	30.0	32.0	35.0	37.0	39.0	41.0
2006[†]										
66–75	159	35.6[a]	3.2	31.0	32.0	33.0	35.0	37.0	40.0	41.0
76–85	155	34.6[b]	3.3	28.0	30.0	33.0	35.0	37.0	38.0	40.0
≥86	68	32.7[c]	3.7	25.0	28.0	31.0	32.0	35.0	37.0	39.0

BM: body mass; H: height; AC: arm circumference; TSF: triceps skinfold thickness; CC: calf circumference; X: mean values; SD: standard deviation.

[†]Statistical differences among age groups, $P < 0.05$ (equal superscript letters: no statistical differences between age groups; different superscript letters: statistical differences between age groups).

[§]Statistical differences between genders.

[#]Statistical differences between 2000 and 2006.

Table 3: Percentile distribution of anthropometric indicators of women by age group (SABE Survey, São Paulo, Brazil, 2000–2006).

Age groups (years)	N	X	SD	Percentiles						
				5	10	25	50	75	90	95
BMI (kg/m^2)										
2000[†]										
60–69[§]	290	28.0[a]	4.9	21.2	22.8	24.3	27.1	30.7	35.1	37.3
70–79[§]	243	27.9[a]	5.7	18.9	20.9	23.6	27.8	31.2	35.1	37.1
≥80	75	26.4[b]	4.9	18.4	19.2	23.5	26.1	30.4	32.4	33.5
2006[†]										
66–75[§]	290	27.6[a]	5.1	20.1	21.2	24.1	26.9	30.6	34.4	36.1
76–85[§]	243	26.7[a]	5.7	18.8	20.0	22.6	26.3	30.3	34.6	36.1
≥86	75	24.8[b]	4.6	17.5	18.6	21.2	24.7	27.8	32.4	33.6
WC (cm)										
2000[#]										
60–69[§]	292	94.0	13.0	74.0	78.0	85.0	93.0	102.0	110.0	115.0
70–79	246	95.7	14.4	72.0	77.0	85.0	96.0	106.0	114.0	118.0
≥80	77	93.6	12.6	73.0	74.0	87.0	94.0	102.0	111.0	115.0
2006[#]										
66–75[§]	292	89.1	11.6	72.0	74.0	81.0	88.0	97.0	104.0	108.0
76–85	246	89.1	12.6	70.0	73.0	80.0	89.0	97.0	105.0	110.0
≥86[§]	77	85.9	12.9	63.0	70.0	77.0	86.0	95.0	105.0	109.0
WHR										
2000[#]										
60–69[§]	292	0.90	0.08	0.76	0.78	0.83	0.90	0.96	1.00	1.02
70–79[§]	244	0.91	0.08	0.79	0.81	0.85	0.91	0.97	1.01	1.04
≥80	77	0.91	0.07	0.80	0.81	0.86	0.91	0.97	1.01	1.02
2006$s^{\S\#}$										
66–75	292	0.87	0.07	0.75	0.78	0.82	0.86	0.91	0.97	1.00
76–85	244	0.88	0.09	0.78	0.79	0.84	0.87	0.92	0.96	1.00
≥86	77	0.87	0.08	0.75	0.78	0.82	0.87	0.91	0.95	1.03
AMC (cm)										
2000[†]										
60–69	294	23.2[a]	2.7	19.1	20.1	21.3	23.0	24.9	26.2	27.8
70–79	260	22.8[ab]	2.9	18.7	19.4	20.8	22.7	24.4	26.3	28.1
≥80[#]	93	22.0[b]	2.3	17.6	18.7	20.7	22.1	23.8	24.6	25.8
2006[†]										
66–75	294	23.4[a]	2.9	18.7	19.8	21.3	23.4	25.3	27.3	28.7
76–85	260	22.8[a]	3.7	17.3	18.6	20.3	22.4	24.8	27.2	30.7
≥86[#]	93	20.7[b]	2.7	15.6	16.9	19.1	20.7	22.7	24.2	24.9
AMA (cm^2)										
2000[†§]										
60–69	294	36.9[a]	10.8	22.5	25.6	29.7	35.5	42.8	48.1	55.0
70–79	260	35.6[a]	11.1	21.4	23.6	28.0	34.7	41.1	48.6	56.4
≥80[#]	93	32.5[b]	8.0	18.2	21.2	27.5	32.3	38.4	41.7	46.6
2006[†]										
66–75	294	37.8[a]	11.1	21.4	24.8	29.8	37.1	44.6	52.6	59.1
76–85[§]	260	36.0[a]	14.7	17.4	21.0	26.4	33.4	42.6	52.4	68.6
≥86[#]	93	28.3[b]	8.7	12.9	16.3	22.7	27.7	34.6	40.1	42.9

BMI: body mass index; WC: waist circumference; WHR: waist-hip ratio; AMC: arm muscle circumference; AMA: arm muscle area; X: mean values; SD: standard deviation.

[†]Statistical differences among age groups, $P < 0.05$ (equal superscript letters: no statistical differences between age groups; different superscript letters: statistical differences between age groups).

[§]Statistical differences between genders.

[#]Statistical differences between 2000 and 2006.

Table 4: Percentile distribution of anthropometric indicators of men by age group (SABE Survey, São Paulo, Brazil, 2000–2006).

Age groups (years)	N	X	SD	Percentiles						
				5	10	25	50	75	90	95
BMI (kg/m^2)										
2000†										
60–69§	157	25.9^{a}	3.6	19.8	21.9	23.8	25.8	27.7	30.3	32.1
70–79§	146	25.3^{ab}	3.8	18.7	20.9	23.0	25.1	27.6	30.1	31.9
≥80	58	24.8^{b}	3.6	19.7	20.1	22.5	24.7	27.1	28.8	30.9
2006†										
66–75§	157	25.4^{a}	3.8	19.0	20.7	23.0	25.1	28.0	29.8	32.5
76–85§	146	24.7^{ab}	3.9	18.5	19.7	22.4	24.4	27.1	29.6	31.0
≥86	58	23.5^{b}	3.3	18.0	19.8	21.3	23.3	25.6	28.3	30.1
WC (cm)										
2000										
60–69§	157	96.8	10.5	81.0	84.0	90.0	96.0	104.0	109.0	112.0
70–79	149	95.2	10.1	76.0	82.0	89.0	95.0	101.0	105.0	113.0
≥80	61	93.8	11.1	77.0	78.0	86.0	94.0	101.0	108.0	110.0
2006										
66–75§	157	93.5	10.6	77.0	80.0	87.0	94.0	100.0	106.0	113.0
76–85	149	91.8	10.8	74.0	77.0	85.0	92.0	99.0	106.0	110.0
≥86§	61	91.2	9.4	76.0	78.0	84.0	91.0	98.0	103.0	110.0
WHR										
2000										
60–69§	157	0.97	0.06	0.88	0.89	0.93	0.97	1.01	1.04	1.05
70–79§	149	0.96	0.06	0.86	0.88	0.93	0.96	1.01	1.03	1.04
≥80	61	0.94	0.08	0.80	0.85	0.91	0.95	0.99	1.03	1.03
2006§										
66–75	157	0.96	0.09	0.83	0.86	0.91	0.96	1.00	1.05	1.08
76–85	149	0.95	0.07	0.83	0.86	0.91	0.95	0.99	1.03	1.06
≥86	61	0.94	0.07	0.83	0.85	0.88	0.95	0.99	1.03	1.05
AMC (cm)										
2000$^{\dagger\#}$										
60–69	159	25.9^{a}	2.4	22.0	22.8	24.3	25.8	27.5	28.8	29.9
70–79	155	25.1^{ab}	2.7	21.0	21.7	23.8	25.3	26.5	28.2	28.9
≥80	65	24.4^{b}	2.3	21.0	21.4	22.6	24.3	26.3	27.6	27.7
2006$^{\dagger\#}$										
66–75	159	24.3^{a}	2.5	20.5	21.2	22.7	24.1	26.0	27.7	28.5
76–85	155	22.9^{b}	2.6	18.5	19.3	21.0	22.9	24.5	26.2	27.5
≥86	65	21.9^{b}	2.4	18.6	18.8	20.7	22.1	23.2	24.7	27.0
AMA (cm^2)										
2000$^{\dagger\S\#}$										
60–69	159	43.7^{a}	10.3	28.5	31.3	36.9	43.0	50.3	56.0	60.9
70–79	154	40.6^{b}	9.8	25.0	27.6	35.3	41.1	46.1	53.4	56.3
≥80	65	37.6^{b}	9.1	25.0	26.5	30.7	37.2	45.0	50.6	50.9
2006$^{\dagger\#}$										
66–75	294	37.6^{a}	9.8	23.6	25.7	30.9	36.2	43.7	51.1	54.8
76–85§	260	32.2^{b}	9.6	17.2	19.8	25.2	31.8	37.9	44.6	50.3
≥86	93	28.7^{c}	8.6	17.5	18.0	24.0	28.8	32.9	38.4	48.1

BMI: body mass index; WC: waist circumference; WHR: waist-hip ratio; AMC: arm muscle circumference; AMA: arm muscle area; X: mean values; SD: standard deviation.

†Statistical differences among age groups, $P < 0.05$ (equal superscript letters: no statistical differences between age groups; different superscript letters: statistical differences between age groups).

§Statistical differences between genders.

$^{\#}$Statistical differences between 2000 and 2006.

in endocrine function, loss of neuromuscular function, muscle fiber atrophy, changes in protein metabolism (deficit between synthesis and degradation), and insufficient protein intake and/or inadequate nutrition [33].

The decrease in skeletal muscle mass occurs primarily as a result of a condition referred to as sarcopenia, and its consequences involve reduced muscular strength and an increased risk of falls and consequent hip fractures [34, 35]. According to Zhu et al. [36], regardless of the risk of falling, the low body reserves have been linked to higher rates of all-cause mortality in women in the United States. Therefore, the skeletal muscle and fat mass reductions may be relevant risk factors with advancing age for disease prevention.

In this study, the reduction in the mean values of TSF with advancing age was greater than that of WC, the lowest values being found among the oldest old, as in other longitudinal studies conducted in China, the United States, and Europe [14–19]. Women have higher mean values of TSF, but the reduction of these variables was greater in men, as observed by Going [20], who adopted the same age groups as used in this study (60–69, 70–79, and ≥80 y), that identified decreases of 23%, 14%, and 20%, in women, and 10%, 12%, and 13%, in men, respectively.

The mean values of WC and WHR also showed a reduction in both genders and all age groups, in line with the data given by previous studies [14, 15, 17]. These values, in Brazilian aged people, are lower than those of a study conducted in a sample of American older adults [19]. This difference is probably due to the fact that the average values of BM and TSF in American old people, as well as of the prevalence of obesity among them, are higher.

It is important to underscore that anthropometric measurements were performed by certified technicians in both periods following SABE standardized protocol [9] but the technical error of measurement was not tested and provided. In this study only the triceps skinfold was included and could have been affected by possibly larger inter- and intraindividual errors of measurements. However, among the assessed anthropometric variables, the most pronounced reduction was observed in the triceps skinfold (30%) and even if less precise measurements were presented we could still probably detect a trend for a decrease from 2000 to 2006.

In conclusion, a negative anthropometric profile appears to be more delayed in women whereas the reduction is more pronounced in the older adults ≥80 years. This study showed that the changes of anthropometric variables associated with the human aging process should be recognized by health professionals as an increased risk of undernutrition among very old adults may be expected. This information should contribute to the formulation of public health policies for disease prevention and health promotion in the elderly population.

Disclosure

The authors declare that this paper represents an original study and has not been published previously. It is not currently being considered by any other journal and once accepted by Journal of Obesity will not be published elsewhere without the written consent of Journal of Obesity. All the authors have seen and approved the content of this paper.

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Research Article

Ultrasound Estimates of Visceral and Subcutaneous-Abdominal Adipose Tissues in Infancy

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Other imaging techniques to quantify internal-abdominal adiposity (IA-AT) and subcutaneous-abdominal adiposity (SCA-AT) are frequently impractical in infants. The aim of this study was twofold: (a) to validate ultrasound (US) visceral and subcutaneous-abdominal depths in assessing IA-AT and SCA-AT from MRI as the reference method in infants and (b) to analyze the association between US abdominal adiposity and anthropometric measures at ages 3 months and 12 months. Twenty-two infants underwent MRI and US measures of abdominal adiposity. Abdominal US parameters and anthropometric variables were assessed in the Cambridge Baby Growth Study (CBGS), $n = 487$ infants (23 girls) at age 3 months and $n = 495$ infants (237 girls) at 12 months. US visceral and subcutaneous-abdominal depths correlated with MRI quantified IA-AT ($r = 0.48$, $P < 0.05$) and SCA-AT ($r = 0.71$, $P < 0.001$) volumes, respectively. In CBGS, mean US-visceral depths increased by ~20% between ages 3 and 12 months ($P < 0.0001$) and at both ages were lower in infants breast-fed at 3 months than in other infants. US-visceral depths at both 3 and 12 months were *inversely* related to skinfold thickness at birth ($P = 0.03$ and $P = 0.009$ at 3 and 12 months, resp.; adjusted for current skinfold thickness). In contrast, US-subcutaneous-abdominal depth at 3 months was *positively* related to skinfold thickness at birth ($P = 0.004$). US measures can rank infants with higher or lower IA-AT and SCA-AT. Contrasting patterns of association with visceral and subcutaneous-abdominal adiposities indicate that they may be differentially regulated in infancy.

1. Introduction

Childhood obesity has become a major public health issue and its prevalence is increasing worldwide [1–3]. More important than BMI, or overall adiposity, greater abdominal distribution of adiposity is associated with insulin resistance, dyslipidemia, hyperinsulinemia, and hypertension [4–6]. In obese children, greater internal-abdominal adiposity (IA-AT), also known as visceral fat, is associated with less favourable metabolic profiles [7, 8]. In addition, subcutaneous-abdominal adipose tissue (SCA-AT) is also associated with insulin resistance and metabolic disorders in some studies [9, 10].

Several epidemiological studies have reported that early life factors, such as impaired fetal growth or excess postnatal weight gain, are associated with later obesity and related comorbidities [11–15]. Growth in fetal life as well as in infancy has been associated with subsequent abdominal adipose tissue accumulation [11, 16]. However, those studies used indirect measures of abdominal adiposity, such as skinfold thickness and waist-hip ratio, and therefore could not distinguish between IA-AT and SCA-AT compartments. Computed tomography (CT) and magnetic resonance imaging (MRI) are considered the gold standards for the assessment of IA-AT and SCA-AT. However, their use is limited in research studies in young children due to high sensitivity to movement

Table 1: Infants characteristics in the Cambridge Baby Growth Study with ultrasound measures at 3 months, 12 months and both at 3 and 12 months[1].

	US at 3 months only		US at 12 months only		US at 3 and 12 months	
	Boys	Girls	Boys	Girls	Boys	Girls
	$n = 67$	$n = 60$	$n = 108$	$n = 100$	$n = 187$	$n = 173$
Birth						
Gestational age at birth (weeks)	39.6 ± 1.4	39.9 ± 1.2	39.8 ± 1.8	39.9 ± 1.1	39.8 ± 1.5	39.7 ± 1.6
Weight (kg)	3.5 ± 0.5	3.4 ± 0.5	3.5 ± 0.6	3.4 ± 0.4	3.5 ± 0.5	3.4 ± 0.5
Length (cm)	51.7 ± 2.4	51.0 ± 2.8	51.5 ± 2.2	51.0 ± 2.1	51.7 ± 2.8	51.7 ± 2.8
Ponderal index (kg/m^3)	25.3 ± 3.2	26.0 ± 2.7	26.0 ± 3.6	26.0 ± 3.2	25.6 ± 3.2	25.9 ± 3.1
Sum of skinfolds (cm)	2.5 ± 0.6	2.5 ± 0.6	2.4 ± 0.5	2.5 ± 0.6	2.4 ± 0.6	2.5 ± 0.6

[1]Data are means (±standard deviations).
US: ultrasound.

artefacts, exposure to ionising radiation (CT only) and need for expensive equipment and specialist technicians [17, 18]. MRI has previously been used to quantify IA-AT and SCA-AT at birth [19]. However, between ages 3-4 months and around 5-6 years, MRI is not feasible in research studies as sedation or even general anaesthesia is required. Therefore research studies in infants usually use anthropometry to evaluate adiposity. However, these measures do not differentiate between IA-AT and SCA-AT.

Ultrasound (US) has been assessed as a noninvasive estimate of IA-AT and SCA-AT. US-visceral depth and US abdominal-subcutaneous depth have been shown to be reliable and reproducible estimates of IA-AT and SCA-AT, respectively, when compared to CT or MRI in adults and in adolescents [20–24]. However, its validity has not been studied in infants. We therefore tested the validity of US-visceral depth and US-abdominal subcutaneous depth by comparison to MRI measures of IA-AT and SCA-AT volumes in newborn infants. In addition, we used this technique to analyze the cross-sectional and prospective associations between US abdominal adiposity and anthropometric variables in the first year of life of a large birth cohort study.

2. Population and Methods

2.1. Validation Study. The validation study was carried out in a convenience sample of 22 healthy term singleton newborn infants (10 boys and 12 girls). Mothers and babies were recruited from the Neonatal Unit and postnatal wards of the Chelsea and Westminster Hospital, London, UK, between 2008 and 2009 and attended the Robert steiner MRI Unit, Hammersmith Hospital, London, UK. This study was approved by the Hammersmith and Queen Charlotte's & Chelsea Hospital research ethics committee. Written parental consent was obtained prior to the participants' visit.

2.2. Cambridge Baby Growth Study (CBGS). Details of the study have been described elsewhere [25]. Briefly, mothers were recruited from the Rosie Maternity Hospital, Cambridge, UK, between 2001 and 2009 at their first antenatal clinic by trained paediatric research nurses. The study comprises a total of 1655 live births. Offspring were followed up at birth 3 and 12 months. At the 3-month visits, a questionnaire on feeding practice, whether breast, formula milk, or mixed, was administered to the mothers. In September 2006, abdominal US was introduced to the follow-up protocol at ages 3 and 12 months and the current analysis is based on those infants with follow-up assessments between September 2006 and June 2010. In total, 487 infants (254 boys and 233 girls) had US measures at 3 months and 495 infants (258 boys and 237 girls) at 12 months. US measures at both 3 and 12 months were available in 360 infants (187 boys and 173 girls). Longitudinal data from birth were available on length, weight and skinfold thickness. No significant differences were observed between infants who had US only at 3 months, infants who had US only at 12 months, and those who had US at both 3 and 12 months with regard to gestational age, anthropometry at birth, and at 3 months (Table 1). Ethical approval was given by the Cambridge local research ethics committee and written informed consent was obtained from the mothers.

2.3. Anthropometry. In the validation study, weight, length, and waist circumference (WC) were measured by one of three trained clinical research fellows. Weight was measured using a Marsden Professional Baby Scale (London, UK) and recorded to the nearest 0.1 kg. Crown-heel length was measured with a Rollameter, a recumbent infant board with a sliding footboard (Raven Equipment Ltd., Dunmow, Essex, UK). WC was measured at the midpoint between the inferior border of the costal margin and the anterior superior iliac crests using a D-loop tape measure (Chasmors Ltd., London, UK) [26].

In CBGS, infants were measured at birth, 3 months, and 12 months by trained paediatric nurses or research assistants. Weight was measured to the nearest 1 g using a SECA 757 digital scale (Chasmors Ltd.) and length using a Kiddimeter (Chasmors Ltd). WC was measured as described previously. Triceps, quadriceps, flank, and subscapular skinfold thicknesses were measured in triplicate on the left side of the body using Holtain calipers (Chasmors Ltd). The triceps skinfold was measured halfway between the acromial process and the olecranon. The quadriceps skinfold was taken from a vertical line over the quadriceps muscle at midline of the thigh, and half way between the top of the patella and the

inguinal crease. The flank (posterior suprailiac) skinfold was taken from the diagonal plane in line with the natural angle of the iliac crest taken in the posterior axillary line immediately posterior to the iliac crest. The skinfold was taken at the oblique angle below the left scapula [26]. Ponderal index was calculated as weight (kg)/length (m)^3. SD scores (SDS) were derived for weight and length by comparison to the 1990 British reference [27]. Separate internal SDS were calculated for each skinfold thickness [=(individual measurement *minus* cohort mean)/cohort SD], and then the overall skinfold thickness SDS was calculated as the mean of the four skinfold SD scores in each individual. The relative intraobserver technical error of measurement (TEM) for length ranged between 0.03% and 0.05%, for quadriceps ranged between 0.4% and 0.6%, for triceps ranged between 1.9% and 2.4%, for subscapular ranged between 1.7% and 2.8% and for flank ranged between 0.8% and 2.0%. The relative interobserver TEM was 0.7% for length, 2.0% for quadriceps, 2.9% for subscapular, 2.2% for triceps, 3.2% for flank. The calculations were based on repeated measurements in 12 infants.

2.4. Ultrasound (US) Abdominal Depths. US-visceral depth and US-subcutaneous-abdominal depth were measured using a Logiq Book XP ultrasound, with a 3C MHZ -RS abdominal curved array transducer (both from GE Healthcare, Bedford, UK). For both measures, the transducer was positioned where the xiphoid line intercepted the WC measurement plane, and the images were taken during expiration. US-visceral depth was measured on a longitudinal plane with a probe depth of 9 cm and was defined as the distance between the peritoneal boundary and the corpus of the lumbar vertebra. US-subcutaneous abdominal depth was measured at the same location, but on a transverse plane with a probe depth of 4 cm, and was defined as the distance between the cutaneous boundary and the linea alba. The image was captured when the transducer just had contact with the skin to avoid compressing the subcutaneous adipose area. In the validation study, the US measures were performed by one of two trained operators and in CBGS by one of four trained operators. The relative intraobserver technical error of measurement (TEM) ranged between 0.3% and 1.7% for US-visceral depth, and 1.1% and 2.6% for US-subcutaneous-abdominal depth, and the relative interobserver TEM was 3.2% for US-visceral depth 3.6% for US-subcutaneous-abdominal depth, based on repeated measurements in 12 infants. In the validation study, qualitative information on the feasibility and acceptability of US was collected from the participants using open-ended questions.

2.5. Magnetic Resonance Imaging (MRI). The MRI procedure used in the validation study is described elsewhere [19]. Briefly, infants were scanned on the same day of the US measurements while in natural sleep, securely swaddled and wearing protective ear muffs, in a 1.5 T Philips Acheiva scanner (Best, Netherlands) using a rapid T1-weighted spin-echo sequence (repetition time 600 ms, echo time 16 ms, field of view =24 cm, number of signal averages =2, and a 256 × 256 matrix with phase conjugate symmetry). Five mm-thick contiguous transverse images throughout the body were obtained and were analysed using SliceOmatic (Tomovision, Montreal, QC, Canada), a semiautomated program containing a threshold range and a contour-following algorithm with an interactive slice editor facility to distinguish between adipose tissue compartments. IA-AT and SCA-AT volumes were calculated from the adipose tissue in the slices from the top of the sacrum to the slice containing the top of the liver or base of the lung [19]. Total body subcutaneous adipose tissue (total SC-AT) was also calculated and comprised both superficial and deep-subcutaneous adipose tissues [28].

2.6. Statistical Analyses. Statistical analyses were performed using STATA version 11.0 (StataCorp Ltd.). Means and standard deviations are presented separately for boys and girls and sex differences were tested using unpaired *t*-tests. For validation purposes, Pearson's correlation coefficients were used to describe the associations between IA-AT or SCA-AT and the US and anthropometric variables. Multiple regression was used to test the added contribution of US depths to anthropometry in explaining the variance in IA-AT or SCA-AT including the root mean square error (RMSE).

For CBGS, Pearson's correlation coefficients were used to describe cross-sectional associations between US depths at 3 or 12 months and anthropometric variables. Associations between growth parameters at birth (birth weight and skinfolds SDS) and US depths at 3 or 12 months were tested using linear regression models. Associations were similar in both sexes, so all analyses were performed in the total sample with adjustment for sex. Further adjustment for current size (weight or skinfolds SDS) was included in the final models. Colinearity between parameters in the same model was quantified using the variance inflation factor (VIF); models with VIF > 5 were considered invalid [29]. To explore the strength of tracking in visceral and subcutaneous-abdominal depths, we performed Pearson's correlations in the 360 infants with US measures at both 3 and 12 months. Weak tracking was defined by a correlation coefficient <0.3, moderate tracking as 0.3–0.6, and strong tracking as >0.6 [30].

All body composition variables and the residuals of the regression models were normally distributed. Statistical significance was set at $P < 0.05$.

3. Results

3.1. Validation Study. In the 22 newborn infants, mean range for age was 10.6 (6–19) days; gestational age at birth 39.9 (37.1–40.8) weeks; weight 3.3 (2.5–3.9) kg; length 53.1 (47–57) cm; WC 34 (29–39) cm; IA-AT 18 (8–32) cm^3, SCA-AT 104 (59–202) cm^3; US-visceral depth 2.0 (1.2–3.0) cm; and US-subcutaneous abdominal depth 0.30 (0.2–0.4) cm.

IA-AT showed moderate positive correlations with US-visceral depth ($r = 0.48$; $P = 0.02$) and US-subcutaneous abdominal depth ($r = 0.52$; $P = 0.01$), and these were higher than with any anthropometric variable (Table 2).

Table 2: Validation study: intercorrelations between MRI IA-AT or SCA-AT and anthropometry or ultrasound measures in 22 term infants.

	IA-AT (cm^3)[1]	SCA-AT (cm^3)[2]	Total SC-AT (cm^3)[3]	Ponderal Index (kg/m^3)	Length (cm)	Weight (kg)	US-SC-abdo depth (cm)[4,5]	US-visceral depth (cm)[4]
SCA-AT (cm^3)[2]	0.48*	1						
Total SC-AT (cm^3)[3]	0.61*	0.94**	1					
Ponderal Index (kg/m^3)	0.15	0.32	0.27	1				
Length (cm)	0.34	0.40*	0.54*	−0.40*	1			
Weight (kg)	0.39	0.6*	0.70**	0.2	0.81**	1		
US-SC-abdo depth (cm)[4,5]	0.52*	0.71**	0.78**	0.17	0.79**	0.92**	1	
US-visceral depth (cm)[3]	0.48*	0.22	0.31	0.14	0.31	0.40*	0.38	1
Waist (cm)	0.08	0.16	0.26	0.19	0.54*	0.72**	0.6*	0.28

Values are Pearson's correlation coefficients.
* P value < 0.05; ** P value < 0.001.
[1]IA-AT: internal-abdominal adipose tissue volume by MRI.
[2]SCA-AT: subcutaneous-abdominal adipose tissue volume by MRI.
[3]Total SC-AT: total body subcutaneous adipose tissue volume by MRI.
[4]US: Ultrasound.
[5]SC-abdo depth: subcutaneous-abdominal adipose tissue depth.

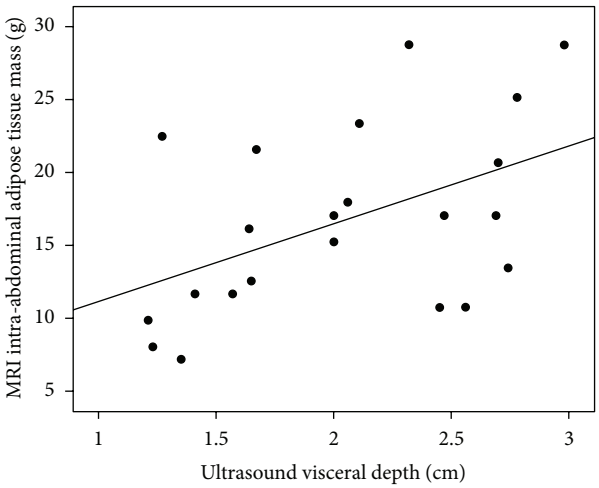

Figure 1: Scatterplot of ultrasound visceral depth against MRI intra-abdominal adipose tissue (IAT-AT) mass. Correlation coefficient: $r = 0.48$; $P = 0.02$.

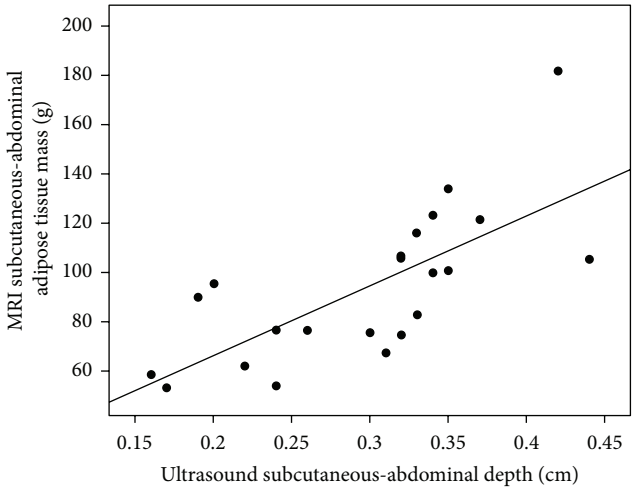

Figure 2: Scatterplot of ultrasound subcutaneous-abdominal depth against MRI subcutaneous-abdominal adipose tissue (SCAT-AT) mass. Correlation coefficient: $r = 0.71$; $P < 0.001$.

SCA-AT was most strongly positively correlated with US-subcutaneous abdominal depth ($r = 0.71$; $P = 0.002$), followed by weight ($r = 0.60$; $P = 0.003$). US-subcutaneous abdominal depth was also strongly positively correlated with total SC-AT ($r = 0.78$; $P < 0.0001$), weight ($r = 0.92$; $P < 0.0001$), and length ($r = 0.79$; $P < 0.0001$). Examination of scatter plots (Figures 1 and 2) showed no obvious heteroscedasticity (i.e., the degree of scatter did not change with increasing IA-AT or SCA-AT). In the multiple regression models (Table 3), the addition of US-visceral depth to weight, sex, age, and US-subcutaneous abdominal depth improved the explained variance in IA-AT from 43% to 62% (P value for model change = 0.02). For the prediction of SCA-AT, the addition of US-subcutaneous abdominal depth to weight, sex and age improved the explained variance from 44% to 65% ($P = 0.1$). Accordingly, addition of the US parameters substantially reduced the root mean square error (RMSE) terms for SCAT-AT for IA-AT (Table 3).

Eleven mothers provided qualitative comments regarding the measurements. Nine mothers commented favourably on the shorter duration of US compared to MRI, and four commented favourably on the lack of separation from their infants using US.

3.2. Abdominal Ultrasound in the Cambridge Baby Growth Study. Characteristics of CBGS infants with US measures at age 3 months ($N = 487$) or 12 months ($N = 495$) are summarised in Table 4. Boys had higher birth weights and birth lengths but lower skinfold thicknesses at birth compared to girls ($P < 0.0001$), despite no difference in gestational age ($P > 0.05$). Boys remained heavier and taller than girls at

Table 3: Prediction models for IA-AT and SCA-AT in the validation study.

	Model[1]	Constant	$B^6 \pm$ SE Weight (kg)	Sex	Age (days)	US SC-abdo depth (cm)[4,5]	US-visceral depth (cm)[4]	R^2 (%)	RMSE[7]	P value for model change
IA-AT (cm^3)[2]	1	−1.4	5.9 ± 3.1	—	—	—	—	15	61.3	*0.07*
	2	−1.5	5.7 ± 3.4	0.4 ± 3.1	—	—	—	16	59.8	*0.1*
	3	−0.7	4.8 ± 3.4	−0.8 ± 3.2	0.3 ± 0.3	—	—	22	60.0	*0.2*
	4	23.7	−12.9 ± 8.0	−0.3 ± 2.9	0.4 ± 0.3	113.8 ± 45.4	—	43	53.4	*0.1*
	5	20.9	−15.0 ± 6.7	2.7 ± 2.6	0.5 ± 0.2	116.6 ± 38.1	6.6 ± 2.3	62	37.4	*0.02*
SCA-AT (cm^3)[3]	1	−42.6	43.6 ± 12.9	—	—	—	—	36	38.2	*0.003*
	2	−48.6	36.2 ± 13.2	19.8 ± 12.2	—	—	—	44	37.4	*0.01*
	3	−49.4	37.1 ± 14.0	21.0 ± 13.2	−0.3 ± 1.2	—	—	44	34.8	*0.02*
	4	66.7	−47.4 ± 0.03	23.4 ± 0.01	0.08 ± 0.09	540.0 ± 171.4	—	65	20.2	*0.1*

[1]Covariables were added sequentially to the prediction models to demonstrate their incremental benefits.
[2]IA-AT: internal-abdominal adipose tissue volume by MRI.
[3]SCA-AT: Subcutaneous abdominal adipose tissue volume by MRI.
[4]US: Ultrasound.
[5]SC-abdo: subcutaneous-abdominal.
[6]B: regression coefficient (±respective standard error).
[7]RMSE: root mean square error.
[8]R^2: coefficient of determination.

3 and 12 months, and boys had slightly greater mean US-visceral depth than girls at 12 months ($P = 0.04$) but not at 3 months ($P = 0.9$).

Mean US-visceral depth at age 12 months was 22% higher in boys and 17% higher in girls at 12 months than at 3 months. In contrast, mean US-subcutaneous abdominal depth and skinfold thickness did not change with age. The apparent increase in US-visceral depth was confirmed in the 360 infants with repeat measures at both 3 and 12 months (mean change: +0.4 cm; $P < 0.0001$). In this longitudinal sample US-visceral depth showed only weak tracking between 3 and 12 months ($r = 0.11$; $P = 0.04$). In contrast the inter-correlation coefficients between 3–12 months were stronger for mean skinfold thickness SDS ($r = 0.30$; $P < 0.0001$), ponderal index ($r = 0.30$; $P < 0.0001$), US-subcutaneous abdominal depth ($r = 0.40$; $P < 0.0001$), WC ($r = 0.50$; $P < 0.0001$), weight ($r = 0.70$; $P < 0.0001$), and length ($r = 0.73$; $P < 0.0001$). Despite these marked changes during infancy, US-visceral depths were consistently lower at both 3 and 12 months in infants who were exclusively breast-fed at age 3 months compared to other infants (at 3 months: mean ± SD: 2.3 ± 0.6 versus 2.4 ± 0.6 cm, $P = 0.04$; at 12 months: 2.7 ± 0.5 versus 2.8 ± 0.5 cm, $P = 0.05$). US-visceral depth was unrelated to time from last feed at 3 months ($r = -0.01$, $P = 0.8$) and 12 months ($r = -0.06$, $P = 0.1$).

3.3. Abdominal Ultrasound Depth Related to Infancy Growth. In cross-sectional analyses (Table 5), US-visceral depth was positively associated with ponderal index at 3 months ($P = 0.02$) and with mean skinfold thickness SDS at 12 months ($P = 0.02$). In contrast, US-subcutaneous abdominal depth at both 3 and 12 months was positively associated with all measures of current body size ($P < 0.005$).

Table 4: Summary of measurements in Cambridge Baby Growth Study infants.

	Boys	Girls	P value[1]
Birth	$n = 362$	$n = 333$	
Gestational age at birth (weeks)	39.8 ± 1.6	39.9 ± 1.3	*0.6*
Weight (kg)	3.5 ± 0.5	3.4 ± 0.4	*0.006*
Length (cm)	51.5 ± 3.5	51.0 ± 2.6	*0.004*
Ponderal index (kg/m^3)	26.0 ± 3.4	26.0 ± 3.1	*0.2*
Sum of skinfolds (cm)	2.4 ± 0.6	2.5 ± 0.6	*0.04*
3 months[2]	$n = 254$	$n = 233$	
Weight (kg)	6.4 ± 0.83	5.8 ± 0.7	*<0.0001*
Length (cm)	61.8 ± 2.5	60.2 ± 2.5	*<0.0001*
Ponderal index (kg/m^3)	27.0 ± 2.1	27.0 ± 2.4	*0.1*
Sum of skinfolds (cm)	4.4 ± 0.8	4.4 ± 0.8	*0.6*
US-visceral depth (cm)	2.3 ± 0.6	2.3 ± 0.6	*0.9*
US-subcut abdo depth (cm)	0.4 ± 0.1	0.4 ± 0.1	*0.7*
12 months[3]	$n = 258$	$n = 237$	
Weight (kg)	10.2 ± 1.1	9.6 ± −1.1	*<0.0001*
Length (cm)	76.4 ± 2.7	74.9 ± 2.6	*<0.0001*
Ponderal index (kg/m^3)	23.0 ± 1.6	23.0 ± 1.8	*0.7*
Sum of skinfolds (cm)	4.3 ± 0.8	4.5 ± 0.8	*0.01*
US-visceral depth (cm)[4]	2.8 ± 0.6	2.7 ± 0.5	*0.04*
US-subcut abdo depth (cm)[4]	0.4 ± 0.1	0.4 ± 0.1	*0.6*

Data are means (±standard deviation).
[1]Student's t-test was used to compare boys versus girls.
[2]3-month ultrasound measurements were performed in 487 infants (254 boys and 233 girls).
[3]12-month ultrasound measurements were performed in 495 infants (258 boys and 237 girls).
[4]US: ultrasound.

In models without adjustment for current body size, US-visceral depth at 3 months ($P = 0.06$) and 12 months

Table 5: Cross-sectional correlations between anthropometry[1] and abdominal ultrasound measures at 3 months (487 infants) and 12 months (495 infants). Data are Pearson's coefficients.

	US-visceral depth		US-subcutaneous abdominal depth	
	3 months	12 months	3 months	12 months
Anthropometry at 3 months				
Weight SDS	0.02		0.31**	
Length SDS	−0.05		0.20**	
Ponderal index SDS	0.11*		0.27**	
Mean of skinfolds SDS	0.05		0.31**	
Anthropometry at 12 months				
Weight SDS		0.03		0.30**
Length SDS		0.00		0.11**
Ponderal index SDS		0.04		0.26**
Mean of skinfolds SDS		0.10*		0.30**

[1]SDS: sex- and age-adjusted standard deviation scores.
[2]US: ultrasound.
*$P < 0.05$, **$P < 0.005$.

Table 6: Associations between size at birth and ultrasound abdominal depth measurements at 3 months (487 infants) and 12 months (495 infants).

	Birth weight SDS		Mean skinfold thickness SDS at birth	
	$B \pm$ SE[1]	P value	$B \pm$ SE[1]	P value
Model 1				
US-visceral depth (cm)				
3 months	−0.024 ± 0.027	*0.4*	−0.059 ± 0.031	*0.06*
12 months	−0.041 ± 0.024	*0.09*	**−0.062 ± 0.028**	**0.03**
US-subcut abdo depth (cm)				
3 months	0.005 ± 0.005	*0.3*	**0.015 ± 0.005**	**0.004**
12 months	0.002 ± 0.004	*0.6*	0.007 ± 0.005	*0.1*
Model 2				
US-visceral depth (cm)				
3 months	−0.041 ± 0.031	*0.2*	**−0.073 ± 0.033**	**0.03**
12 months	−0.045 ± 0.026	*0.09*	**−0.073 ± 0.028**	**0.009**
US-subcut abdo depth (cm)				
3 months	**−0.012 ± 0.005**	**0.01**	0.005 ± 0.005	*0.3*
12 months	**−0.011 ± 0.004**	**0.01**	0.002 ± 0.005	*0.7*

Results are shown before (Model 1) and after (Model 2) adjustment for body size at the time of the ultrasound measurement.
Model 1: adjusted for sex.
Model 2: also adjusted for current weight or skinfolds, respectively.
[1]B: Regression coefficient (and respective standard error); this represents the SD change in each parameter per 1 SDS change in birth weight or skinfold thickness at birth.

($P = 0.03$) showed *inverse* trends or associations with skinfold thickness at birth, and these inverse associations strengthened on adjustment for current skinfold thickness (at 3 months: $P = 0.03$; at 12 months: $P = 0.009$) (Table 6). In contrast, US-subcutaneous abdominal depth at 3 months was *positively* associated with skinfold thickness at birth ($P = 0.004$), but not at age 12 months ($P = 0.1$) and no associations remained on adjustment for current skinfolds (Table 6). In unadjusted models no US measure was associated with birth weight; inverse associations between birth weight and US-subcutaneous abdominal depth at 3 and 12 months only emerged after adjustment for current body weight ($P = 0.01$ at both 3 and 12 months).

4. Discussion

Our validation study results showed that US abdominal depth provides acceptable accuracy in estimating IA-AT and SCA-AT volumes assessed by MRI in infants. The US measures showed stronger correlations with IA-AT and SCA-AT than did the traditional anthropometric variables, and the addition of US measures to those variables substantially improved the predictions of IA-AT and SCA-AT. The precision of our models was significantly improved as RMSE for IA-AT and SCA-AT substantially decreased. Furthermore, the reproducibility and reliability of the US measures were high as indicated by low inter- and intraobserver technical errors of

measurement. In addition, the ultrasound method was highly acceptable to parents as it was faster to perform than MRI and no separation from their infants was required. By contrast, the actual MRI scanning time is approximately 12 minutes, but the whole procedure including preparation time to settle the infant can take up to one hour.

We acknowledge that our validation study has some limitations. In particular, it was performed in newborns at age range 6–19 days, rather than at 3 or 12 months as in CBGS. This is because the reference imaging techniques, MRI and CT, are not feasible for research studies at those later ages, as discussed previously. However, our findings are consistent with positive reports in adults and adolescents comparing abdominal US to MRI [20–23, 31, 32]. In contrast, our earlier validation study in young children aged 6-7 years old showed only weak correlations between US-measures and IA-AT, which was assessed in that study by single-slice CT at L4-L5 corresponding to the location of the US probe [33]. A few other studies have used a different US technique, the abdominal adipose tissue index, which is the ratio between the preperitoneal fat thickness and subcutaneous fat thickness [18, 34]. However, that technique has only been validated in adults [35, 36] and in one study of 34 children aged 1–18 years (only 9 were between 1 and 4 years old) [35, 36]. Further US validation studies are required in other childhood age groups using multiple slice assessment of IA-AT volumes as the reference.

Secondly, the sample size in our validation study was small ($n = 22$). In fact this study had 80% power to detect a Pearson's correlation coefficient higher than 0.56 with a type I error of 5%. Our inclusion criteria were limited to only healthy newborns (birth weight range 2.5–3.9 kg) due to the need to travel to a research site some miles from their place of birth. We anticipate that the inclusion of infants with more extremes of underweight/thinness and macrosomia would increase the strength of the observed correlations. We were unable to test absolute validity using the Bland-Altman analysis because this method requires the different measurements to be reported in the same units in order to calculate the degree of bias on the raw measurement scale. In addition, no existing prediction equations were available for IA-AT and SC-AT from US measures based on US measures in this age group. Future independent studies should test the absolute validity of the prediction models derived in this study. However, our main purpose was not to develop prediction models, but rather to analyze the associations between anthropometric variables, age, and gender with US parameters.

Finally, the correlation between US-visceral depth and IA-AT was only moderate ($r = 0.48$; $P = 0.02$). Indeed, US-subcutaneous abdominal depth showed a slightly stronger correlation with IA-AT ($r = 0.52$; $P = 0.01$), but was more strongly related to SCA-AT and hence US-visceral depth was the more specific marker of IA-AT. In contrast, the correlations between US-visceral depth and IA-AT were 0.80–0.82 in older adults and 0.64–0.72 in adolescents [20–24]. Lower IA-AT volumes in infants might contribute to these lower correlations. Also, in our experience measurement of US-visceral depth in infants is more susceptible to bowel peristalsis and movement artifacts than in older age groups; however US-visceral depth was unrelated to time from last feed. While more accurate markers would provide greater power for subsequent studies [37], such correlations are of similar strength as other proxy measures used in large epidemiological studies tools to assess physical activity and dietary behaviours. For example, questionnaire estimates of energy expenditure show correlations of 0.20 to 0.67 with the doubly labelled water reference techniques [38, 39], and questionnaire estimates of nutrient intakes show correlations of ~ 0.5 with nutritional biomarker references [40]. Therefore, we consider that US abdominal depth is suitable to rank infants with higher or lower abdominal adipose tissue volumes.

In the CBGS cohort study, we found that infants with lower skinfold thickness at birth tended to have *lower* subcutaneous abdominal depth at age 3 months, but *greater* visceral depths at ages 3 and 12 months, suggesting a differential regulation of these adipose tissue compartments. The stronger visceral depth associations that we observed with lower skinfold thickness at birth rather than lower birth weight suggest that these birth measures may be proxies for fetal growth restraint during the later antenatal period. In support of this notion, our previous studies using MRI in newborns reported that growth-restricted and extremely preterm infants have reduced SCAT but preserved IA-AT mass [19, 28]. Our findings of differential changes in visceral compared to subcutaneous abdominal depths with age and by sex further support the active partitioning of adipose tissue between these compartments during infancy.

We also observed that the associations between skinfold thickness at birth and infancy visceral depth strengthened with further adjustment for current skinfold thickness. Some investigators have argued that adjustment for current size could potentially introduce bias due to overcontrolling [41]. However, such adjustment can be justified if current body size is a potential confounder that is positively associated with both birth size and the outcome of interest. Our interpretation is in line with Lucas and colleagues [42], who have argued that if an association with birth size becomes apparent or is amplified after adjustment for current size, then it is the postnatal change in size between birth and followup that influences the outcome, rather than an antenatal factor.

Therefore, postnatal factors related to infancy gains in skinfold thickness may influence the accumulation of visceral adipose tissue at 3 and 12 months. Our observation of weak tracking in visceral depth indicates wide between-individuals variation in the rate of accumulation of visceral adipose tissue during infancy, although measurement error and imprecision are likely contributing factors to this estimate. Our observed associations with breastfeeding indicate that postnatal nutrition may influence the accumulation of visceral adipose tissue in infancy.

In conclusion, US abdominal depths were better than anthropometric measures in ranking infants with higher or lower IA-AT and SCA-AT volumes and may be applicable to large epidemiological studies at young ages when MRI and CT imaging techniques are infeasible. Application of these US measures in a large birth cohort study showed that visceral and subcutaneous-abdominal depths differed in their

changes with age and in their patterns of association with antenatal and postnatal factors, suggesting that IA-AT and SCA-AT may be differentially regulated in the first year of life.

Conflict of Interests

None of the authors had any conflict of interest.

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Research Article

Body Fat and Body-Mass Index among a Multiethnic Sample of College-Age Men and Women

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Obesity prevalence and average body composition vary by US race and gender. Asian Americans have the lowest prevalence of obesity. Relying on body-mass index (BMI) to estimate obesity prevalence may misclassify subgroups that appear normally weighted but have excess body fat. We evaluated percentage body fat (PBF) and BMI to determine whether BMI reflects PBF consistently across different races. 940 college students were recruited from a local public university over four consecutive years. We measured PBF by bioelectrical impedance analysis (BIA), weight by physicians' scales, and height with stadiometers. Our sample comprised Asians (49%), Caucasians (23%), Hispanics (7%), and Other (21%). Participants averaged 21.4 years old; BMI was 22.9 kg/m^2; PBF was 24.8%. BMI and PBF varied significantly by race and gender (P value = 0.002 and 0.005 for men; 0.0009 and 0.0008 for women). Asian-American women had the lowest BMI (21.5 kg/m^2) but the second highest PBF (27.8%). Linear association between BMI and PBF was the weakest ($r^2 = 0.09$) among Asian-American women and BMI had the poorest sensitivity (37%) to detect PBF. The high PBF with low BMI pattern exhibited by Asian-American women suggests that they could escape detection for obesity-related disease if BMI is the sole measure that estimates body composition.

1. Introduction

Body-mass index (BMI), an important indicator of obesity prevalence in large populations, generally reflects degree of fatness among individuals. Body-mass index can however over- or underestimate adiposity depending upon certain circumstances.

Accurate determination of obesity has become exceedingly important because of major health threats posed by excess adiposity. Obesity is associated with increased incidence of cardiovascular disease, diabetes, sleep apnea, degenerative joint disease, and site-specific cancers [1–6]. Moreover, high obesity prevalence could potentially result in shortened life expectancy in the coming years [7] and excess mortality [8, 9]. Because of the present and future health problems associated with excess adipose tissue, underestimation of obesity, particularly in young adults who might otherwise appear to have normal BMI measures, could lead to false conclusions about body composition and future health status. Underestimation of body fatness in young women for instance may be problematic for future risk of diseases such as breast cancer. Patterns of excess adipose tissue established early in adulthood could promote the occurrence of obesity at menopause, a known risk factor for breast cancer [10–12].

Validation studies have evaluated accuracy of BMI in estimating body fatness, by comparison to more refined measures such as bioelectric impedance analysis (BIA) and dual energy absorptiometry (DXA) [13–21]. Some studies observed low sensitivity of BMI to detect obesity in general [14, 20], while others concluded that BMI was most inaccurate in detecting obesity among intermediate ranges of BMI [13, 17, 20, 21]. In addition accuracy of BMI to detect body fatness appears to be affected by ethnicity [15, 18–20], gender [17, 21], and age [13, 19–21].

The prevalence of inactivity has increased among all age groups and is thought to be a major contributor to the

obesity epidemic [22]. With the rise in sedentary behavior, potentially greater numbers of young and middle aged adults may be susceptible to accumulation of unhealthy amounts of adipose tissue without significant weight change. We undertook a study of young adult college age adults to examine the relationships between percentage body fat and body-mass index among a multiethnic sample living in Southern California.

2. Materials and Methods

2.1. Study Population. Serial cross-sectional samples of college-age men and women were recruited during winter quarter of four consecutive years, 2006, 2007, 2008, and 2009 from an undergraduate physiology course at a major public university in Southern California. All 1029 students in the course over the three years were eligible and subsequently enrolled (241 in 2006, 242 in 2007, 239 in 2008, and 307 in 2009) into the study. Data from 940 students with complete covariate information were included.

2.2. Human Research. The study was approved by the Institutional Review Board of the University of California at Los Angeles. We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during this research.

2.3. Demographic Variables. Ethnicity and racial background were self-identified using the following categories: White/Caucasian; Hispanic; Black/African American; Middle Eastern; Indian; Native American; Asian (Eastern); Asian (Southeast); Pacific Islander; and Other. A blank space to write in "Other" was provided, and, additionally, multiple categories could be marked in the event of mixed race or ethnicity. Age was self-reported.

Because of small numbers of individuals in some of the racial/ethnic groups and to increase the power of our stratified analyses we combined race/ethnicity into four groups: Asian, White, Hispanic, and Other. Eastern and Southeastern Asian groups were combined into Asian. Other category consisted of multiple ethnicities, recorded Other, Middle Eastern, Native American, African American, and Pacific Islanders. Self-reported White/Caucasian and Hispanic were retained as singular categories.

2.4. Anthropometric Measurements. Trained clinical technicians conducted all anthropometric measurements. Subjects were weighed while wearing no shoes. Body weight was measured with a physicians' scale. Heights were taken with a stadiometer (Detecto-Medic; Detecto-Scales; Brooklyn, NY).

Bioelectrical impedance analysis (BIA), used to estimate percent body fat (PBF) and fat and fat free mass, was conducted with a quadripolar BIA device (310e Bioimpedance analyzer; Biodynamics, Inc., Seattle, WA). Fat-free mass and fat mass are estimated with a regression equation based on data obtained through comparison with bioimpedance estimates with hydrodensitometry (Biodynamics, Inc., Seattle, WA). The equation used by the present study, and also utilized in our earlier study [13], estimates $\text{FFM} = (a \times \text{Ht}^2) + (b \times \text{Wt}) + (c \times A) + (d \times R) + e$, where FFM is fat-free mass, Ht is height (cm), Wt is weight (kg), A is age (years), and R is impedance (Ω). The constants, a through e, are proprietary information of Biodynamics, Inc. We utilized the model for estimation of FFM for our entire study population. We constructed categories of body-mass index using the WHO International Criteria for all populations (<18.5 kg/m^2; 18.5–24.9 kg/m^2; 25–29.9 kg/m^2; >30 kg/m^2) [23], and the WHO criteria for Asian populations with suggested public health action (<23 kg/m^2; 24–27.5 kg/m^2; 27.6–32.49 kg/m^2; ≥32.5 kg/m^2) [24]. Since there are no accepted cutpoints for percentage body fat [25], we utilized the PBF cutpoints defined in Okorodudu et al., 2010, a diagnostic performance meta-analysis of BMI in relationship with percentage of body fat [26].

2.5. Statistical Analysis. Analysis of variance was used to evaluate differences in anthropometric variable means according to race and gender. We further analyzed associations between BMI and PBF by constructing multiple linear regression models adjusting for gender and ethnicity and linear regression models of BMI and PBF according to whether Asian or Caucasian separately for males and females. We plotted scatter distributions of BMI and PBF for Asian and Caucasian males and females.

To provide estimates of sensitivity and specificity of BMI to predict PBF, we evaluated distributions of gender and ethnic subgroups according to BMI and PBF. If we consider PBF measured by BIA as the gold standard, we computed sensitivity as the proportion of participants classified as obese by BMI (≥30.0 kg/m^2) and PBF (≥25.0% for men and ≥30.0% for women) divided by the total classified as obese by PBF. We computed specificity as the proportion of participants classified as nonobese (normal or overweight) by BMI (<30.0 kg/m^2) and nonobese (normal or overweight) by PBF (<25.0% for men and <30% for women) divided by the total classified as nonobese by PBF [27]. We restricted our estimation of sensitivity and specificity to Asian-Americans and Whites because the other ethnic groups had insufficient numbers to provide stable estimates.

All data analyses were performed using the Statistical Analysis System Version 9.2 (Statistical Analysis System 2008, Cary, NC, USA). All reported P values assume a two-sided alternative hypothesis. P values less than or equal to 0.05 were considered significant.

3. Results

Most study participants (see Table 1) were Asian-American (49%), with 23% White, 7% Hispanic, and 21% Other. Most were females (60%). Age distribution was fairly narrow, with subjects averaging 21 years old (standard deviation was 1.6 years). Average body-mass index (BMI) was 23 kg/m^2, weight 65.4 kg (145 pounds), and height 169 centimeters (cm) (66 inches). Total PBF estimated by BIA was 25%. Fat mass averaged 17 kilograms (kg); fat-free mass 49 kg.

Table 1: Characteristics of the study population.

Variable	Category	N	Percent
Racial composition	East Asian	364	37.92
	SE Asian	96	10.00
	African American	11	1.15
	Hispanic	68	7.08
	Indian	51	5.31
	Middle Eastern	86	8.96
	Pacific Islander	27	2.81
	White	216	22.50
	Other	41	4.27
Combined racial groups	Asian, no Pac Islander	475	49.48
	White	216	22.50
	Hispanic	68	7.08
	Other, Inc Pac Isl, Mixed	201	20.94
Gender	Male	380	39.58
	Female	580	60.42
Body-mass index (WHO-International)*	<18.5	74	7.71
	18.5–24.9	664	69.17
	25.0–29.9	170	17.71
	30.0+	52	5.42
Body mass index (WHO-Asian populations)**	<18.5	74	7.71
	18.5–22.9	481	50.10
	23.0–27.49	296	30.83
	27.5+	109	11.35
Percent body fat	<20.0	230	23.96
	20.0–24.9	227	23.65
	25.0–29.9	291	30.31
	30.0+	212	22.08
Age (years)	Mean		21.40
	S.D.		1.64
Body mass index	Mean		22.95
	S.D.		3.82
Weight (kg)	Mean		65.37
	S.D.		14.74
Height (m)	Mean		1.69
	S.D.		0.09
Total percent body fat	Mean		24.82
	S.D.		6.94
Fat body mass (kg)	Mean		16.52
	S.D.		11.4
Fat-free body mass (kg)	Mean		49.15
	S.D.		11.76

*WHO: see [23].
**WHO: see [24].
S.D.: standard deviation.

Almost all anthropometric measures were significantly different according to race and according to gender and race (see Table 2). Hispanics and men of other ethnicities had the highest BMI, both averaging 26 kg/m^2 and 25 kg/m^2, respectively, while Hispanic females (mean = 30%), Asian females (mean = 28%), and Other females (mean = 29%) had the highest percentage body fat. Asian-American males (mean = 174 cm) (68 inches) and Asian-American females (mean = 161 cm) (63 inches) were the shortest among the racial/ethnic subgroups.

Results from multiple linear regression analyses suggested that 52% of the variability ($r^2 = 0.52$) in PBF was explained by BMI, ethnicity, and sex. We further compared degree of association between BMI and PBF for both Asian-Americans and Whites by constructing separate scatter plots for males and females (see Figures 1 and 2). In addition we computed fit of association between BMI and PBF using linear regression models. Among men, the association between BMI and percent body fat was fairly strong and linear for Asian-Americans ($r^2 = 0.47$) and less precisely associated for Whites ($r^2 = 0.34$). Among females however the association was weaker, particularly among Asian-Americans ($r^2 = 0.09$).

We utilized the WHO International (BMI $\geq$ 30.0 kg/m^2) and the WHO Asian (BMI $\geq$ 27.5) cutpoints for obesity [23, 24] and subclassified according to PBF cutpoints for men ($\geq$25%) and women ($\geq$30%) defined in Okorodudu et al. [26] to estimate frequency of individuals who were correctly classified by BMI and individuals who were not (see Table 3). If we consider PBF as a more accurate estimation of obesity, the sensitivity of BMI to predict PBF in Asian-American men was 91%. Among Asian-American women however, the sensitivity was much lower at 37% (see Table 3). Specificity in Asian-American women was higher at 81%, while the specificity of BMI to predict nonobese PBF was poorer in Asian-American men (63%). Whites showed a similar pattern to Asian-Americans, although the differences were less striking. The sensitivity of BMI to predict PBF among White men (70%) was higher than White women (50%), while the reverse was true for specificity. The specificity of BMI to predict non-obese PBF was higher among White women (98%) compared to White men (72%).

4. Discussion

Our study was designed to evaluate relationships between percentage body fat and body-mass index among a multiethnic sample of college-age men and women living in Southern California. We were interested in determining the extent to which excess adiposity might be occurring among normal to intermediate ranges of body-mass index and whether these relationships may vary according to gender and ethnicity. We utilized comparative measures between body-mass index and percentage body fat to characterize instances where low degree of association may represent elevated body fat in the context of normal BMI measurements.

We studied college-age young adults because this age group, in particular, may be more likely to have BMI measurements in the normal to intermediate range. The average body-mass index for US men (27 kg/m^2) and women (26.5 kg/m^2)

Table 2: Study population characteristics according to race/ethnicity and according to race/ethnicity and gender.

Characteristic	Asian		White		Hispanic		Other		P value
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	
Overall study population									
Age (years)	21.16	1.31	21.66	2.14	21.93	2.12	21.52	1.45	0.0001
Height (cm)	165.89	8.78	172.49	8.99	168.48	9.91	168.91	9.53	0.0001
Body weight (kg)	61.79	13.08	69.07	14.16	69.80	17.07	68.36	16.15	0.0001
BMI (kg/m^2)	22.31	3.37	23.09	3.60	24.32	4.70	23.84	4.40	0.0010
Percent body fat	24.57	6.97	23.67	6.55	27.30	6.73	25.81	7.06	0.0020
Fat mass (kg)	15.17	5.51	16.41	6.4	19.19	7.54	17.57	6.91	0.0600
Fat-free mass (kg)	46.62	10.82	53.31	10.93	50.69	12.59	50.85	12.76	0.0001
Males									
Age (years)	21.12	1.36	21.95	2.69	22.71	3.00	21.51	1.66	0.0020
Height (cm)	174.22	6.30	179.02	2.81	177.44	7.14	176.53	7.21	0.0001
Body weight (kg)	72.33	13.37	78.04	11.17	82.46	15.49	78.88	13.83	0.0001
BMI (kg/m^2)	23.74	3.73	24.38	3.23	25.85	4.54	25.36	3.74	0.0020
Percent body fat	18.86	7.73	19.62	5.86	22.74	6.36	21.81	5.95	0.0005
Fat mass (kg)	14.26	7.40	15.74	6.28	19.38	8.37	17.30	6.96	0.0005
Fat-free mass (kg)	58.03	7.49	62.30	7.58	63.30	9.30	61.60	9.37	0.0010
Females									
Age (years)	21.19	1.29	21.43	1.56	21.50	1.28	21.54	1.26	0.0600
Height (cm)	161.24	6.15	167.36	6.71	163.58	7.49	162.59	5.92	0.0001
Body weight (kg)	55.92	8.41	62.02	12.16	62.90	13.68	59.65	12.32	0.0001
BMI (kg/m^2)	21.51	2.87	22.07	3.56	23.48	4.62	22.58	4.51	0.0009
Percent body fat	27.75	4.71	26.85	5.17	29.78	5.58	29.12	6.15	0.0008
Fat mass (kg)	15.67	4.11	16.94	6.47	19.09	7.14	17.79	6.90	0.0010
Fat-free mass (kg)	40.26	6.18	45.09	7.26	43.81	7.97	41.96	7.26	0.0001

BMI: body-mass index.

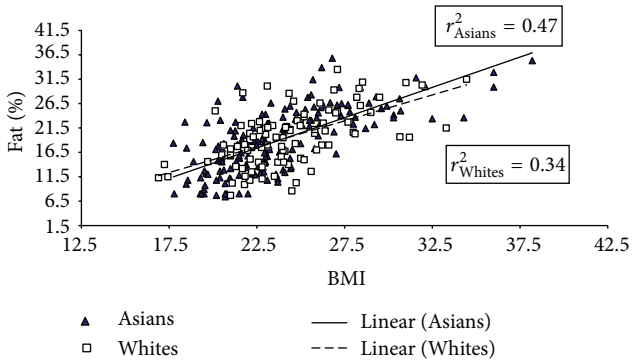

Figure 1: Distribution of body-mass index and percentage body fat for males according to race/ethnicity.

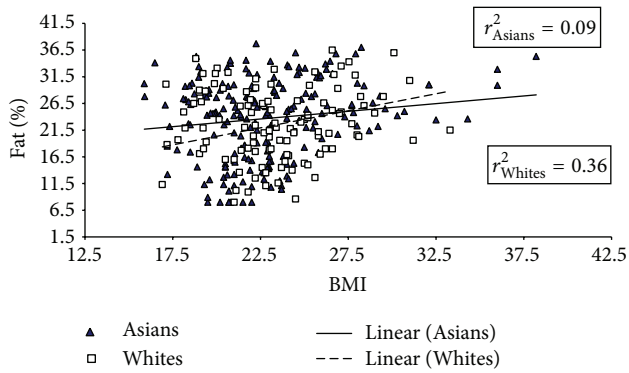

Figure 2: Distribution of body-mass index and percentage body fat for females according to race/ethnicity.

between the ages of 20 are 29 is the lowest of all adult age groups younger than age 80 years [28]. The average BMI in our study population was similar to US population norms. Average BMI for males in our study was 24.4 kg/m^2 and females 22.0 kg/m^2.

Estimates for body composition among the college-aged sample were strikingly different for gender and race. Asian men (23.7 kg/m^2) and women (21.5 kg/m^2) had the lowest mean BMI among the study sample, while Hispanic men (25.9 kg/m^2) and women (23.5 kg/m^2) had the highest mean BMI. Percentage body fat did not follow the same distribution pattern however. While Asian women had the lowest BMI, they did not have the lowest percentage body fat. Asian women had 27.8% body fat, while Caucasian women, lower than Asian women, had 26.9%. Hispanic women had the highest percentage body fat (29.8%).

Table 3: Classification of obesity for Asian-American and US white college age adults using body-mass index and percentage body fat.

		Classification of obesity in US Whites* BMI						Classification of obesity in US Asians** BMI			
		<30.0 kg/m^2		≥30.0 kg/m^2				<27.5 kg/m^2		≥27.5 kg/m^2	
		N	%	*N*	%			*N*	%	*N*	%
Males						Males					
Percentage	<25%	56	71.8	22	28.2	Percentage	<25%	85	63.0	50	37.0
Body fat	≥25%	5	29.4	12	70.6	Body fat	≥25%	3	8.6	32	91.4
Sensitivity	70.6%					Sensitivity	91.0%				
Specificity	71.8%					Specificity	63.0%				
Females						Females					
Percentage	<30%	89	97.8	2	2.2	Percentage	<30%	172	81.1	40	18.9
Body fat	≥30%	15	50.0	15	50.0	Body fat	≥30%	59	63.4	34	36.6
Sensitivity	50.0%					Sensitivity	36.6%				
Specificity	97.8%					Specificity	81.1%				

*WHO: see [23].
**WHO: see [24].
BMI: body-mass index.

The correlation between BMI and PBF for the total sample, while moderate, did not indicate variation according to gender and race subgroups. We computed correlation coefficients between BMI and PBF and found that the overall partial correlation between BMI and percentage body fat in our study population, adjusting for race and gender, was 0.63. Partial correlation for men was 0.63 and women 0.46, both adjusting for race (data not shown). Our correlation for men was similar to a study using the Third NHANES sample [21]. Their study reported a correlation of 0.69 among men in the 20 to 29 age group [21]. Our reported correlation for women (0.46), on the other hand, was much lower than that reported in NHANES (0.89) [21].

Age, gender, and ethnicity have been found in several studies to affect strength of relationship between BMI and percentage body fat [13, 15, 17–21]. In the population-based NHANES III study, correlations became weaker as age increased [21]. A study of body fatness among 706 African Americans and Caucasian men and women in New York City found that older subjects had higher percentage body fat with similar BMI measurements compared to younger subjects from both racial and gender subgroups [29]. In a recent multiethnic population survey from NHANES 1999–2004 of BMI and other anthropometric measures, agreement of BMI with percentage body fat varied significantly by race-ethnicity categories [25]. The present study population consisted of young college-age adults with mean and median ages of 21.5 and 21.0, respectively, suggesting that based on previous studies, we ought to be observing stronger agreement between BMI and percentage body fat.

Gender also affects the degree to which BMI predicts body fat [13, 17, 21, 25, 29]. Females have higher percentages of body fat compared to males of all ages and ethnic groups [21, 25], and, for an equivalent BMI, women have significantly greater amount of total body fat than men throughout the entire adult life span [21]. Among all four ethnic subgroups in the present study, females averaged a higher percentage body fat, but lower BMI than males. In all ethnic groups except Whites, females had weaker associations between percentage body fat and BMI than males.

The relationship between PBF and BMI has been shown to differ according to ethnic origin [30]. A meta-analysis concluded that for the same PBF, African Americans and Polynesians have higher BMI compared to Caucasians. In contrast, Chinese, Ethiopians, and Thai BMI measurements are lower than Caucasians [31]. Other studies of Asians have shown that Taiwanese subjects had a relatively lower BMI but higher PBF than Caucasians [18]. Similarly, Indonesians had higher PBF but lower BMI compared to Dutch Caucasians [32], and Japanese young men living in Japan and Australia had greater body fat distribution but lower BMI compared to Australian Caucasians [19]. In our multiethnic sample of young adults, the linear association between BMI and PBF was stronger for Asian men ($r^2 = 0.47$) than for Caucasian men ($r^2 = 0.34$), while the reverse was true for women. The association between BMI and PBF was the weakest for Asian women ($r^2 = 0.09$) compared to Caucasian women ($r^2 = 0.36$).

High percentage of body fat occurring at lower BMIs has also been observed among younger Japanese in a multinational study of Japanese, Caucasians, and African Americans conducted in Japan, the United Kingdom, and the United States [33]. The study used DXA, underwater weighing, and BMI, to develop prediction formulas that estimated PBF using a four-compartment model. According to their prediction model, Asians had a significantly higher percentage body fat for any given BMI than Caucasians and African Americans [33].

The low degree of association between BMI and PBF that we observed for young Asian-American women in particular may signal a present and future risk for obesity-related disease. BMI was a poor predictor of PBF in Asian-American women reflected by a low sensitivity (37%). The low sensitivity and weak association suggest that use of

BMI to estimate adiposity may be especially inaccurate in Asian-American women. In a comparative study of body composition in Asian and Caucasian young adult females, results showed a similar PBF (31%) for Taiwanese women aged 20 to 29, with a similar BMI (23.7 kg/m^2) that we observed [18]. In a comparative study of prepubertal children from China and New York City, similar correlation patterns were observed with Chinese girls having the highest PBF and lowest BMI compared to girls of other geographic and racial origins [34]. In a large cross-sectional study of adiposity from a medical practice in Manhattan, BMI misclassified 48% of women when DXA was used to validate BMI [35].

Our reliance on BIA to estimate PBF measurement may have contributed to potential inaccuracies in our data. A validation study of body fat estimation by BIA compared to DXA conducted among multiethnic women showed that underestimation of lean body-mass was affected by whether being Caucasian or African American [15], although their study was conducted among overweight to obese women, and whether the same underestimation would occur in a younger normal weighted population with a different ethnic distribution is unclear. In another validation study conducted among 5 European populations, the bias in BIA measurement compared to DXA was minor, particularly among subjects younger than age 35 [16]. Our PBF estimates measured by BIA for Asian females (27.8%) and Asian males (18.9%) are close to the PBF observed among Taiwanese females (30.6%) and males (22%) between the ages of 20 and 29 measured by the DXA [18].

5. Conclusions

In conclusion we observed striking differences in body composition according to gender and ethnicity among a young adult college-age population. While most males and females of different ethnicities had similar associations between PBF and BMI, Asian-American females represented a special subgroup where BMI did not accurately reflect underlying adiposity. The weight and BMI measurements were representative of normal; however the relative high PBF may put Asian-American females at risk for future obesity-related disease.

Abbreviations

PBF: Percent body fat
BIA: Bioelectric impedance analyst
DXA: Dual energy absorptiometry.

Conflict of Interests

The authors have no conflict of interests to report.

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Research Article

Total Body Fat Content versus BMI in 4-Year-Old Healthy Swedish Children

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Childhood overweight and obesity, a worldwide problem, is generally identified using BMI (body mass index). However, this application of BMI has been little investigated in children below 5 years of age due to a lack of appropriate methods to assess body composition. Therefore, we used air displacement plethysmography (ADP) to study 4.4-year old boys and girls since this method is accurate in young children if they accept the requirements of the measurement. The purpose was to analyze the relationship between BMI and body fat in these children. Body composition was assessed in 76 (43 boys, 33 girls) of the 84 children brought to the measurement session. Boys and girls contained 25.2 ± 4.7 and 26.8 ± 4.0% body fat, respectively. BMI-based cut-offs for overweight could not effectively identify children with a high body fat content. There was a significant ($P < 0.001$) but weak ($r = 0.39$) correlation between BMI and body fat (%). In conclusion, requirements associated with a successful assessment of body composition by means of ADP were accepted by most 4-year-olds. Furthermore, BMI-based cut-offs for overweight did not effectively identify children with a high body fatness and BMI explained only a small proportion of the variation in body fat (%) in this age group.

1. Introduction

Childhood overweight and obesity is a growing problem worldwide which, according to the WHO, represents one of the most serious challenges to human health in this century [1]. Globally as many as 42 million children under the age of five were overweight in 2010 [1]. Thus early childhood obesity-prevention interventions represent a rapidly growing research area [2]. For example, Manios [3] has described how a team of 15 partners across the EU are working to develop such a program for children aged 4–6 years. In the USA, Fitzgibbon et al. [4] conducted a pilot intervention study to prevent obesity in 3–5-year-old Latino children, and Taveras et al. [5] tested an intervention in primary care pediatrics including children aged 2–6 years in an attempt to reduce their overweight and obesity. Identification of overweight and obesity in young children is generally based on the BMI (body mass index) of boys and girls from several countries with age- and sex-specific cut-off values for these conditions [6]. However, obesity is characterized by excessive body fat accumulation, and in adults the body fat content for any particular BMI-value is quite variable [7]. Published data suggest that BMI is an inaccurate estimate of body fatness of individuals also in pediatric populations [8]. However, the relationship between BMI and body fatness has been little studied in children below the age of five and no data are available to demonstrate how well the commonly used definition of overweight identifies children with a high body fat content in this age group. This lack of data is likely due to a lack of appropriate body composition methodology. It is therefore of interest to note that the air displacement plethysmography (ADP) technique, a method known to be able to assess body composition accurately in adults [9], has recently been modified for young children. A validation study [10] demonstrated that this method can be accurate also in such subjects provided that measurements are appropriately conducted, which requires that the child accepts to sit alone in a closed chamber during three measurements each

with a duration of about 50 seconds. Unfortunately, this requirement makes it difficult to study children below two years of age. Better compliance can be expected among older children, but it is likely that a certain number of children below the age of five will refuse participation. The aims of this paper were (a) to report the compliance of 4-year-old children when performing the ADP measurement according to established requirements; (b) to describe body fatness, assessed by means of ADP, in a group of healthy 4-year-old boys and girls in relation to commonly used BMI cut-off values for overweight; (c) to assess the relationship between BMI and body fat (%) in 4-year-old boys and girls.

2. Subjects and Methods

2.1. Subjects. Parents who had participated with their children ($n = 110$) in a previous study [11] were asked to let their children participate in the present study and 84 parent couples accepted. The research ethics committee in Linköping approved the study.

2.2. Body Composition. Body volume and density along with body fat were evaluated by means of ADP using the pediatric option with software 5.2.0 (Bod Pod Body Composition System, COSMED USA) [10]. In this procedure body mass is measured using an electronic scale and body volume is assessed in a closed chamber utilizing the relationship between pressure and volume. The principle of the measurement is the same as that for adults [13]. However, volume measurements were always performed in triplicate and strictly according the manufacturer's instructions. Corrections for surface area artifact and thoracic gas volume and calculations of body composition were conducted as described by Fields and Allison [10].

2.3. Weight Status. BMI (kg/m^2) of boys and girls was calculated. Overweight was assessed according to the International Obesity Task Force [6] using age- and-sex specific cut-off values.

2.4. Statistical Analysis. Linear regression analysis was used. Pearson correlation coefficient was calculated and tested for significance. Our sample size ($n = 76$) was sufficient to identify a correlation between BMI and body fat (%) of 0.28 as significant ($P < 0.05$) with a power of 0.8. The comparison of correlation coefficients was based on Fisher's z transformation. Significance (2-sided) was accepted when $P < 0.05$.

3. Results

Body composition was successfully measured in 76 children, equivalent to 90% of the children brought to the examination. These children are described in Table 1. It should be noted that their weight and height are comparable to Swedish reference data as demonstrated by the z-scores given in this table. Figure 1 shows BMI versus body fat (%) for boys (a) and girls (b) in the study together with the appropriate age- and sex-specific cut-offs for overweight. Obviously, children with a high body fat content may well have a BMI below the cut-off for overweight and children with a BMI above this cut-off may well have a comparatively low body fat content. For example, children with a BMI between 15 and 16 had a body fat content ranging from 14.3 to 32.5%. BMI (x) and body fat (%) (y) were significantly but weakly correlated in boys ($r = 0.38$, $P < 0.01$, $y = 1.22x + 5.74$), in girls ($r = 0.46$, $P < 0.01$, $y = 1.66x + 0.63$), and in the sexes combined ($r = 0.39$, $P < 0.001$, $y = 1.32x + 4.94$). The correlation coefficients for boys and girls were not significantly different.

Table 1: Characteristics of boys and girls studied for body composition by means of air displacement plethysmography (boys = 43, girls = 33).

	Boys	Girls
Age at measurement (yr)	4.42 ± 0.09[1]	4.41 ± 0.03[2]
Weight (kg)	18.9 ± 2.2	18.1 ± 2.2
Weight z-score[3]	0.08 ± 1.03	−0.06 ± 0.94
Height (cm)	109 ± 4	107 ± 4
Height z-score[3]	0.15 ± 0.81	−0.12 ± 0.98
BMI (kg/m^2)	15.9 ± 1.5	15.8 ± 1.1
Body fat (%)	25.2 ± 4.7	26.8 ± 4.0

Values are means ± standard deviations. BMI: body mass index.
[1]Range: 4.34–4.96 yr.
[2]Range: 4.34–4.48 yr.
[3]Calculated using reference data for Swedish children [12].

4. Discussion

In this study of 4-year-old boys and girls we found that most children accepted the requirements of the ADP measurement and that BMI-based cut-offs for overweight did not effectively identify children with a high body fat content. We also found weak but significant correlations between BMI and body fatness in boys and girls.

In our study a large proportion of the children brought to the investigation by their parents could be measured with ADP. It is relevant to point out that these parents represented quite a special group since they had previously agreed to participate in a study [11] when their children were newborns. Therefore they represented a selected group that tended to be quite positive towards participation in research. On the other hand, most of them, fathers as well as mothers, were professionally active with busy schedules which may have diminished their possibility to participate with their children in the study. Therefore, our parent population is not necessarily comparable to other parent populations regarding the proportion willing to accept participation in studies. In spite of these considerations, it is important to note that our sample of children is similar to that of healthy Swedish children in general regarding weight and height. In conclusion, our study demonstrated that a large proportion of healthy 4-year-olds who are brought to a measurement session by their parents will accept the requirements of the ADP technique.

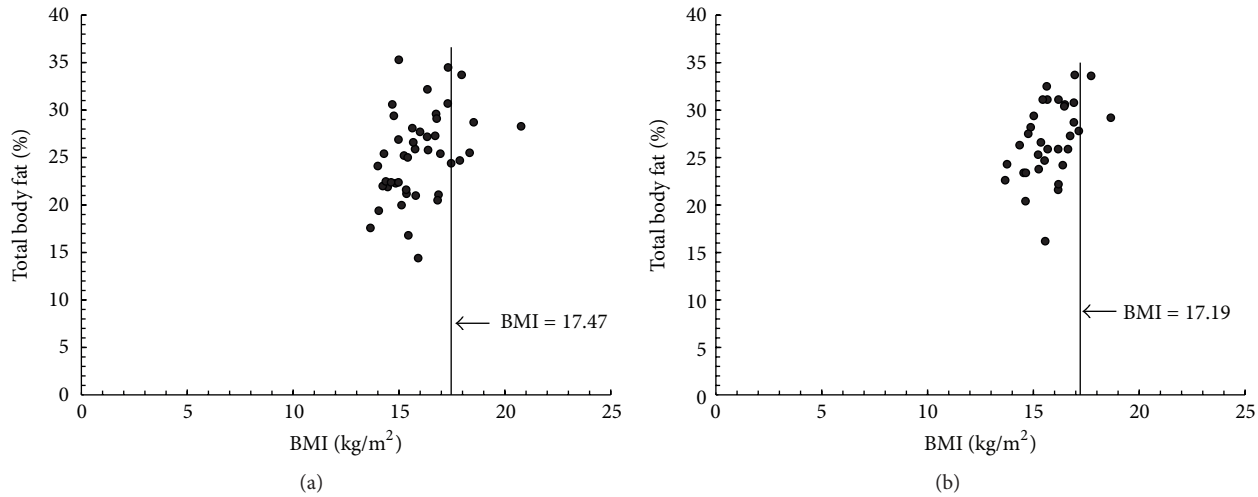

Figure 1: Body mass index (BMI) (kg/m^2) (x) versus total body fat (%) (y) in healthy Swedish 4-year-olds in relation to the age- and sex-specific cut-offs for overweight [6], (a) boys ($n = 43$) with overweight cut-off 17.47, (b) girls ($n = 33$) with overweight cut-off 17.19.

Our study clearly demonstrates that BMI-based cut-offs for overweight do not effectively identify 4-year-old children with a high body fat content. However, a significant correlation between BMI and body fat (%) was found in these children. This relationship appeared to be slightly stronger in girls than in boys but our study may have been too small to identify such a significant difference between the sexes. However, the correlation coefficient for the sexes combined, 0.39, indicates that BMI explained only about 15% of the variation in body fat (%). The corresponding figure for adults is 50–70% [14] and 34–70% for 3–18 year old children [8]. These studies [8, 14] clearly demonstrated that BMI is a poor predictor of the body fat content of individual subjects. The poor correlation between BMI and body fat (%) found in the present study show that this is also the case for 4-year-old children. This finding is likely to have important implications for studies of overweight and obesity in children. For example, our results motivate attempts to include body composition assessment by means of ADP in obesity prevention programs for young children. It is important to realize that such assessments must be properly carried out and that behavioral issues are likely to be a limiting factor in infants and in some young children [15]. Nevertheless, most 4-year-olds accepted the requirements of ADP and therefore this technique can certainly be applied in a large number of young children. Thus it has the potential to be a useful complement to BMI and thereby improve our understanding regarding the biology of childhood obesity development.

In conclusion, requirements associated with successful assessments of body composition by means of ADP, a valid body composition method, were accepted by most 4-year-old children. Therefore this method has the potential to be a useful complement to BMI in studies related to overweight and obesity in this age group. Furthermore, our study showed that BMI-based cut-offs for overweight do not effectively identify 4-year-old children with a high body fat content and that BMI explains only a small proportion of the variation in body fat (%) in this age group.

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Research Article

Comparison among T1-Weighted Magnetic Resonance Imaging, Modified Dixon Method, and Magnetic Resonance Spectroscopy in Measuring Bone Marrow Fat

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Introduction. An increasing number of studies are utilizing different magnetic resonance (MR) methods to quantify bone marrow fat due to its potential role in osteoporosis. Our aim is to compare the measurements of bone marrow fat among T1-weighted magnetic resonance imaging (MRI), modified Dixon method (also called fat fraction MRI (FFMRI)), and magnetic resonance spectroscopy (MRS). *Methods*. Contiguous MRI scans were acquired in 27 Caucasian postmenopausal women with a modified Dixon method (i.e., FFMRI). Bone marrow adipose tissue (BMAT) of T1-weighted MRI and bone marrow fat fraction of the L3 vertebra and femoral necks were quantified using SliceOmatic and Matlab. MRS was also acquired at the L3 vertebra. *Results*. Correlation among the three MR methods measured bone marrow fat fraction and BMAT ranges from 0.78 to 0.88 ($P < 0.001$) in the L3 vertebra. Correlation between BMAT measured by T1-weighted MRI and bone marrow fat fraction measured by modified FFMRI is 0.86 ($P < 0.001$) in femoral necks. *Conclusion*. There are good correlations among T1-weighted MRI, FFMRI, and MRS for bone marrow fat quantification. The inhomogeneous distribution of bone marrow fat, the threshold segmentation of the T1-weighted MRI, and the ambiguity of the FFMRI may partially explain the difference among the three methods.

1. Introduction

Recent studies revealed a negative relationship between bone marrow fat and bone mineral density [1–10]. These studies, along with the cellular level evidences [6, 11–13], suggest that bone marrow fat might play a role in the pathogenesis of osteoporosis [7, 12, 14].

Previous studies have used different methods to measure bone marrow fat. Among the magnetic resonance methods, there are T1-weighted magnetic resonance imaging (MRI), magnetic resonance spectroscopy (MRS), and Dixon method. Each method has its comparative strengths and weaknesses. The T1-weighted MRI is a conventional practice that is familiar to all MR technologists and is therefore not technically demanding in terms of acquisition. T1-weighted MRI also requires less acquisition time than the Dixon method. The Dixon method, also called the water-fat imaging method, fat-water imaging method, or fat fraction MRI (FFMRI), represents a category of magnetic resonance methods that generates water and fat images. So far, there is no consensus on the naming of this group of methods, and for consistency's sake we use FFMRI in the present paper. MRS methods are considered the golden standard in measuring tissue fat but require the technician to prescribe the volume of interest—MRS box in the exact desired location. Consequently, the acquisition of MRS is relatively technical demanding.

Although T1-weighted MRI, MRS, and FFMRI methods have been compared in measuring subcutaneous adipose tissue, visceral adipose tissue, organ fat (i.e., liver), it is important to compare these methods in measuring bone marrow fat for the following reasons: fat fraction of subcutaneous and visceral adipose tissue is high (i.e, ~80%), while fat fraction for liver fat is lower (i.e., <50%); in previous results, comparisons do not cover the full range of fat fraction. In addition, fat within subcutaneous and visceral adipose tissue and liver is usually homogenously distributed. Conversely,

bone marrow fat can distribute inhomogeneously, and its fat fraction can range from 0 to 80% depending on the specific imaging pixel's composition of red marrow and yellow marrow in the pixel [15]. Therefore, comparisons of different MR methods in measuring subcutaneous, visceral adipose tissue or liver fat cannot necessarily be generalized to bone marrow fat measurement. The present report compares T1-weighted MRI, MRS, and FFMRI methods for measuring marrow fat in the L3 vertebra and femoral necks in a group of postmenopausal women.

2. Methods

2.1. Protocol and Design. A total of 27 Caucasian postmenopausal women (age ≥ 50 yrs, BMI 17.4–37.9 kg/m^2) were recruited for the present study. All subjects were established as healthy and completed a medical history screening. Subjects were excluded from undergoing MRI if they had contraindications to MRI such as metal implants, claustrophobia, or weight greater than 300 lbs as per specifications of the scanner manufacturers.

2.2. Magnetic Resonance Imaging

2.2.1. Fat Fraction MRI. Whole-body MRI scans were acquired, as previously reported [16], using a 1.5 T Sigma "LX" system (General Electric, Milwaukee, WI, USA). The protocol involved acquisition of 10 mm thick axial images contiguously of the whole body with a matrix of 256 × 160. Imaging is performed by using a breath-hold dual-echo spoiled gradient-recalled echo sequence (repetition time/echo time (TR/TE), 150 ms/2.1 ms, 4.4 ms) acquired with flip angles of 70° and then 20° to provide T1-weighted and intermediate-weighted images, respectively [16]. A third T1-weighted dual-echo gradient-echo breath-hold gradient-recalled echo sequence (TR/TE, 200 ms/4.6 ms, 9.2 ms; flip angle, 70°) is also performed to calculate T2*. The percentage of bone marrow fat is estimated from both sets of images, and T2* correction is applied. The dual-flip angle images are used to identify whether water or fat is the dominant constituent as previously described [16]. The images were postprocessed in Matlab (MathWorks Inc., Natick, MA, USA) to calculate fat fraction. Bone regions were manually analyzed at the Image Analysis Lab in the New York Obesity Nutrition Research Center by trained, quality-controlled, and cross-validated technicians using image analysis software (SliceOmatic, Tomovision Inc., Montreal, Canada). The bone regions for fat fraction calculation in the present study include the whole L3 vertebra and the femoral neck regions that match the "total hip" regions of the dual-energy X-ray absorptiometry scan of the subject (Figure 1). The intra- and interobserver CV for FFMRI analysis are 0.9% and 2.2%.

2.2.2. T1-Weighted MRI. BMAT of the L3 and femoral necks on T1-weighted MRI (TR/TE, 150 ms/4.4 ms, flip angle, 70°) was segmented at the Image Analysis Laboratory by trained, quality-controlled, and cross-validated technicians using image analysis software (SliceOmatic, Tomovision Inc., Montreal, Canada). The threshold for BMAT segmentation on T1-weighted MRI was set at the same level as subcutaneous adipose tissue on the grey scale. The reader first sets the threshold that best segments subcutaneous adipose tissue on the grey scale [2–4, 17–19], then that threshold is used in the same image to segment BMAT. In the SliceOmatic software package, the segmentation threshold can be freely adjusted and the analyst can view the "preview" of subcutaneous adipose tissue segmentation, which is transparently overlaid on the grey image. When the "preview" of the segmentation best matched the subcutaneous adipose tissue, the corresponding threshold was determined as the threshold to segment BMAT. Tissue compartment volume was calculated as previously described [20]. The intra- and interobserver CV for T1-weighted MRI analysis are 1.0% and 2.6%.

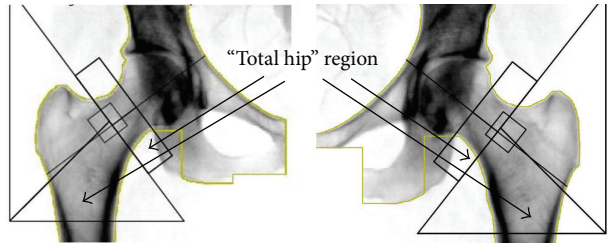

Figure 1: Dual-energy X-ray absorptiometry total hip scan region, which is the sum of the rectangle and triangles and is also the region we used for bone marrow fat quantification of the femoral necks in the present study.

2.3. Magnetic Resonance Spectroscopy. Spine phase-array coil was used for standard PRESS sequence (P.A. Bottomley, US Patent 4480 228 (1984)) MRS acquisition [21]. A PRESS box with dimensions w/2·d/2·h/2 cm^3 was located centrally in the L3 vertebral body (TR/TE 3000/25) [21, 22]. Fat fraction was calculated after spectra are processed by jMRUI (available at http://www.mrui.uab.es/mrui/mrui_Overview.shtml) [21, 22]. Manually selected resonance frequency and line width of water (4.65 ppm) and fat (1.3 ppm) peaks were used as starting values in the nonlinear least squares fitting algorithm. Fat fraction, defined as the relative fat signal intensity amplitude in terms of a percentage of total signal intensity amplitude (S_{fat} and S_{water}), was calculated according to the following equation [6]: Fat fraction = $S_{fat}/(S_{fat} + S_{water})$. The intra- and interobserver CV for MRS are both 0%, due to the automatic process of the algorithm.

2.4. Statistical Methods. Pearson correlation coefficients among bone marrow fat measurements of different methods were calculated for the L3 vertebra and femoral necks. When necessary, variable values were mathematically transformed to normalize the residual distributions. Log transformations were applied initially and followed by Box-Cox transformations if necessary [23].

All statistical analyses were carried out using SAS 9.2 package (SAS Institute. Inc., Cary, NC, USA). Two-tailed ($\alpha = 0.05$) tests of significance were used.

3. Results

3.1. Descriptive Statistics. All subjects ($n = 27$) were postmenopausal Caucasian women and ranged in age from 51 to 61 years (mean ± SD, 55.2 ± 3.3 years). BMI ranged from 17.8 to 37.9 kg/m^2 (mean ± SD, 24.2 ± 4.9 kg/m^2).

3.2. Relationship of Bone Marrow Fat Measurement among T1-Weighted MRI, MRS, and FFMRI in L3 Vertebra. For bone marrow fat measurement in the L3 vertebra, the correlation between Box-Cox-transformed T1-weighted MRI and MRS is 0.88 ($P < 0.001$) (Figure 2(a)). The correlation between T1-weighted MRI and FFMRI was 0.79 ($P < 0.001$) (Figure 2(b)). The correlation between MRS and FFMRI was 0.78 ($P < 0.001$) (Figure 2(c)). We further located the region on FFMRI that best matched the MRS box; the correlation between MRS and FFMRI improved to 0.86 ($P = 0.004$) (plot not shown).

3.3. Relationship of Bone Marrow Fat Measurement among T1-Weighted MRI and FFMRI in Femoral Necks. For bone marrow fat measurement in femoral necks, the correlation between Box-Cox-transformed T1-weighted MRI and FFMRI was 0.86 ($P < 0.001$) (Figure 2(d)). MRS was not acquired in the femoral necks.

4. Discussion

This study compared bone marrow fat measured by three magnetic resonance methods: T1-weighted MRI, MRS, and FFMRI. We have shown good correlations among the three methods. We chose the L3 vertebra and femoral neck because (1) these are the locations that are most frequently used to measure bone marrow fat; (2) a major interest in bone marrow fat measurement is attributed to its relationship with osteoporosis; femoral neck and lumbar spine are the locations used for the diagnosis of osteoporosis. We did not do absolute comparison among the three magnetic resonance methods because the scales of the results of these methods were not the same. In addition, T1-weighted MRI measures adipose tissue amount, while MRS and FFMRI measured fat fraction. Although we used these terms interchangeably, fat and adipose tissue are not the same components [24]. Fat makes up ~80% of adipose tissue, with the rest as water, proteins, minerals, and so forth.

The discrepancy among the three methods can be attributed to several factors. First, MRS measures ~1/8 (i.e., w/2·d/2·h/2) of the total volume of the L3 vertebra, and the MRS volume of interest is located at the center of the vertebra. On the other hand, T1-weighted MRI and FFMRI both measure the entire L3 vertebra. If the distribution of adipose tissue in the cavity of the L3 vertebra is not homogeneous, fat fraction of MRS may not reflect that of the entire vertebra [15]. When we calculated fat fraction on FFMRI in the region that best matches the MRS box region, the correlation between FFMRI and MRS improved (i.e., $r = 0.86$ versus 0.78, $P = 0.004$). However, because MRI was acquired at 1 cm slice thickness, and the L3 vertebra had a height of 2.4–2.9 cm (measured at the center of the vertebra) in this study, FFMRI was subjected to partial volume effect. Another error source of FFMRI was due to the miscalculations at approximately 45% fat content. The FFMRI method use of in-phase and out-of-phase gradient-echo MR imaging was performed with dual-flip angles (70°, 20°) to resolve ambiguity of the dominant constituent (i.e., water or fat). There were algorithmic miscalculations at approximately 45% fat content because of crossover of estimated fat curves [16]. Therefore, pixels of approximately 45% fat content could have been influenced. It should be noted that there are many versions of FFMRI methods available and error source of these methods may be different from the FFMRI method used in the present study both qualitatively and quantitatively [25–27].

The error source of T1-weighted MRI can be attributed both to the partial volume effect of MRI and to the single threshold T1-weighted MRI method being semiquantitative. Only image pixels containing bone marrow adipose tissue that reach a certain threshold were quantified as BMAT on T1-weighted MRI. The T1-weighted MRI method that was used in the present study has not only been validated for quantifying regional adipose tissue volume [28, 29] but has also been widely applied to adipose tissue measurement and serves as a reference method for adipose tissue quantification [30–36]. However, bone marrow fat pixels below the threshold for subcutaneous adipose tissue were not quantified as BMAT in the present study.

4.1. Limitations and Future Directions. FFMRI is a fast evolving field, and there are newer water-fat imaging methods available now [25–27]. The present study only tested one version of the FFMRI methods and the limitation of this version may not necessarily apply to other FFMRI methods. The advantage of this method is that it only uses sequences that are commercially available on almost all MRI scanners. Therefore, this method may be used in multicenter, large clinical trials. On the other hand, most-recently-developed FFMRI methods that are only available on certain MRI scanners may be used for smaller-scale studies that require high accuracy. Future studies may use more advanced FFMRI methods to quantify BMAT and to compare with MRS in quantifying bone marrow fat. Future studies may also evaluate how repositioning of the subject would influence the agreement of bone marrow fat quantification by different methods.

5. Conclusions

There is a good correlation among bone marrow fat measured by T1-weighted MRI, FFMRI, and MRS. The inhomogeneous distribution of bone marrow fat, the threshold segmentation of the T1-weighted MRI, and the ambiguity of FFMRI may partially explain the difference among the three methods in measuring BMAT.

Conflict of Interests

The authors state that they have no conflict of interests.

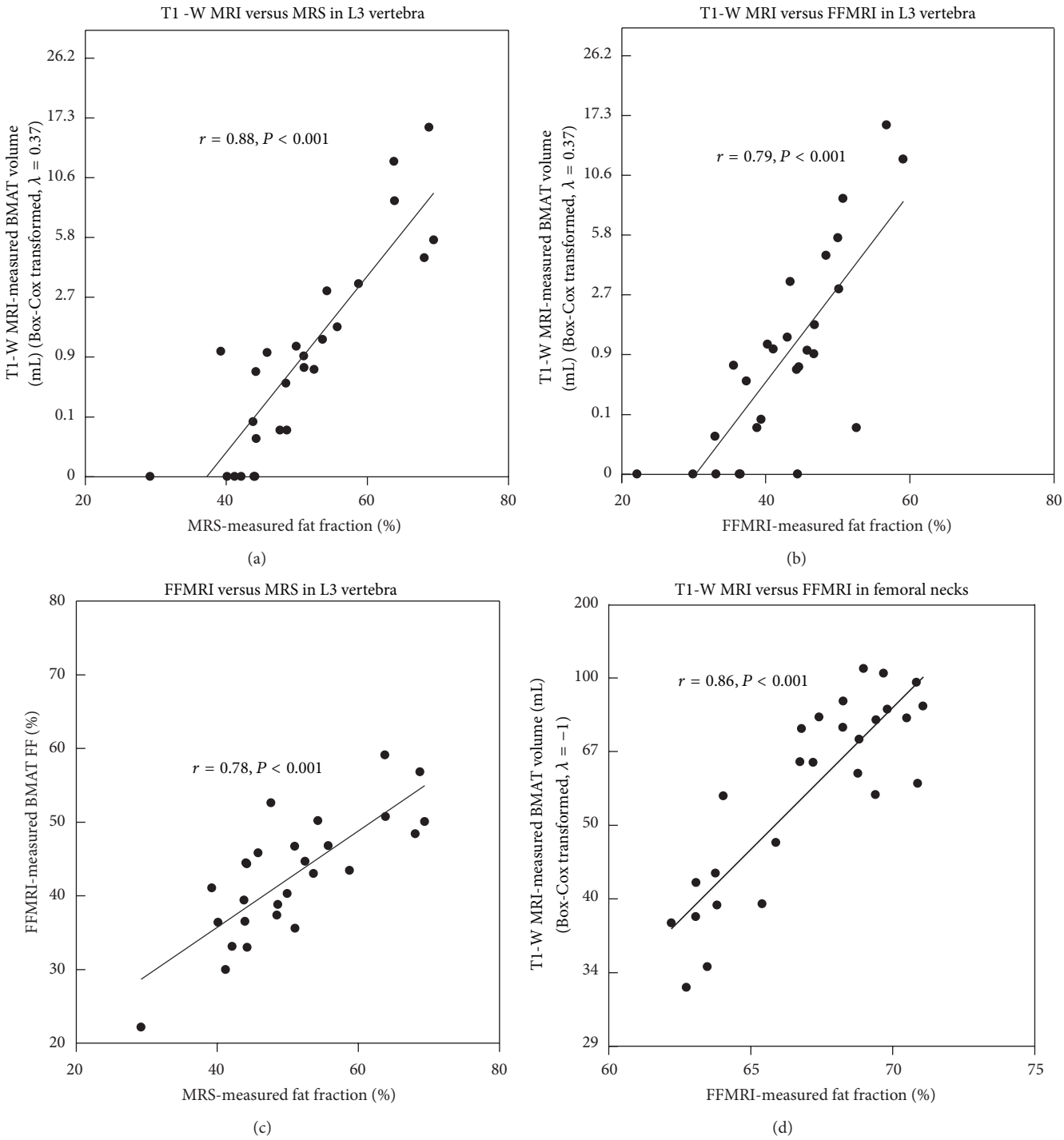

Figure 2: (a) Correlation between BMAT measured by T1-weighted MRI (T1-W MRI) and bone marrow fat fraction (FF) measured by MRS in L3-vertebra; (b) correlation between BMAT measured by fat fraction MRI (FFMRI) and bone marrow fat fraction measured by MRS in L3-vertebra; (c) correlation between BMAT measured by T1-weighted MRI and bone marrow FF measured by FFMRI in L3-vertebra; (d) correlation between BMAT measured by T1-weighted MRI and bone marrow FF measured by FFMRI in femoral necks.

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Research Article

The Multicomponent Anthropometric Model for Assessing Body Composition in a Male Pediatric Population: A Simultaneous Prediction of Fat Mass, Bone Mineral Content, and Lean Soft Tissue

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The aim of this study was to propose and cross-validate an anthropometric model for the simultaneous estimation of fat mass (FM), bone mineral content (BMC), and lean soft tissue (LST) using DXA as the reference method. A total of 408 boys (8–18 years) were included in this sample. Whole-body FM, BMC, and LST were measured by DXA and considered as dependent variables. Independent variables included thirty-two anthropometrics measurements and maturity offset determined by the Mirwald equation. From a multivariate regression model (${}_nY_m = {}_nx_{(r+1)(r+1)}\beta_m + {}_n\varepsilon_m$), a matrix analysis was performed resulting in a multicomponent anthropometric model. The cross-validation was executed through the sum of squares of residuals (PRESS) method. Five anthropometric variables predicted simultaneously FM, BMC, and LST. Cross-validation parameters indicated that the new model is accurate with high R^2_{PRESS} values ranging from 0.94 to 0.98 and standard error of estimate ranging from 0.01 to 0.09. The newly proposed model represents an alternative to accurately assess the body composition in male pediatric ages.

1. Introduction

Estimate body composition of children is not an easy task, since the relationships between body components during growth are not constant as in adults. Anthropometric-based equations remain an adequate alternative for determining the body composition of pediatric populations in field settings. However, the advent of new technologies has enabled new ways for body composition assessment, thus, rendering the traditional anthropometry inaccuracy as a representative standard [1]. There are some methodological concerns when using the current anthropometric models: several equations have been developed using a two-compartment model (2C model) either using hydrostatic weighing [2, 3] or other densitometric techniques; however, this approach relies on assumptions, specifically concerning the fat-free mass (FFM) density (1.1 g/cc) and hydration (73.2% of total-body water within the FFM) that, although stable for adults, may vary substantially during growth. In fact, from childhood through adolescence, total-body water (TBW) decreases whereas bone mass increases which means that FFM density is lower than 1.1 g/cc, at younger ages, approaching that value when chemical maturity is reached [4]. Therefore, 2C models tend to overestimate FM and underestimate FFM in children, and their use as a criterion method for developing anthropometric-based models is inaccurate. For that reason, the use of 3C and 4C compartment models are preferred for determining the body composition in children [4], since fewer assumptions are used as more FFM components are measured.

The advent of dual-energy X-ray absorptiometry (DXA), measures of FM, bone mineral content (BMC), and lean soft tissue (LST) are obtained. Hence, DXA can be considered as a 3C model since the estimates of three components are

obtained as follows: first by separating pixels into those with soft tissue only (FM plus LST) and those with soft tissue plus BMC, based on two different photon energies (lower and higher energies, resp.) [5]. The DXA provides precise [6, 7] and accurate [8–11] measures of FM and FFM (as LST plus BMC) when compared to multicompartment models. In addition, given its low risk and quick assessment, the DXA use has been implemented in large multicenter studies, including the National Health and Nutrition Examination Survey [12].

However, the availability of DXA in the clinical and fields settings is limited given its cost. Therefore, simple solutions are required for estimating body composition in children and anthropometric parameters, such as skinfolds and circumferences, which have been widely used as bedside techniques in different contexts. Thus, the aim of this study was to develop and cross-validate multicomponent-anthropometric-based equations to simultaneously estimate FM, BMC, and LST in a male pediatric population, using DXA as the criterion method.

2. Methods

2.1. Study Population. The study followed a cross-sectional design, consisting of a sample of 408 young males between 8 and 18 years of age. The subjects were recruited voluntarily from a population of students that could be engaged in systematic programs of sports, or not, considered as athletes and nonathletes, respectively. The athletes came from sports centers ($n = 177$) and nonathletes from schools ($n = 231$). Children with a regular sports practice were engaged in soccer field ($n = 143$), athletics ($n = 11$), football court ($n = 20$), and judo ($n = 3$). The nonathletes came from public ($n = 142$) and private ($n = 89$) school. Medical examinations were conducted to assure that children were healthy and not taking medications that could affect metabolism, appetite, or growth. The number of White participants was relatively higher ($n = 270$) compared to Blacks ($n = 79$), Hispanics ($n = 50$), and Asians ($n = 9$), classified by race self-declared. This sample comes from a large ethnic mixture and previous analysis that showed no statistical differences in interracial body composition (data not shown), so, the final samples ($n = 408$) were considered as uniform. To determine the sample size, we followed the Bolfarine and Bussab [13] recommendation, and based on a pilot analysis with subjects presenting a large variance in the dependent variable (FM), the estimation of the desired error (1.25%) and confidence interval (95%) determined that at least 300 subjects would be required.

The study followed the guidelines and regulations of directing human research, and agreements were obtained from the parents or guardians to all procedures. The approval was granted by the Ethics in Research Department of the School of Physical Education and Sport, University of São Paulo (CEP332007/EEFE/04.04.2007-2006/32), which also adhere to the Helsinki Declaration.

2.2. Study Protocol. Each subject was evaluated in the laboratory, in the morning after an overnight fast, in a single session, and always by the same examiner, and all measurements, were performed during a period of three months. Before the measurements the subjects were asked to empty their bladders. Dressed in shorts and shirt, the total-body DXA examination was applied using the system for total-body scan, according to manufacturer's guidelines. The anthropometric measures were performed according to the literature recommendations [14, 15], summarized below.

2.2.1. The Dependent Variables: Dual-Energy X-Ray Absorptiometry. Whole and regional body composition was estimated with a DXA Scanner Lunar DPX-NT (GE Medical, Software Lunar DPX enCORE 2007 version 11.40.004, Madison, WI). The software identified the physical characteristics of ethnicity, gender, and age and automatically adjusted the scan mode, speed, and images resolution.

Body weight was determined from DXA, and the dependent variables of interest were fat mass (FM, kg), bone mineral content (BMC, kg), and lean soft tissue (LST, kg).

2.2.2. The Independent Variables

(1) *Anthropometrics.* The subject body mass, height, and seating height [15] were measured with a digital scale (Filizola, PL 200, Campo Grande, MS) and a fixed wall stadiometer (Sanny Professional-ES2020, São Paulo, SP), respectively. The skinfolds (biceps, triceps, subscapular, chest, midaxillary, suprailiac, vertical abdominal, horizontal abdominal, mid-thigh, and medial calf), circumferences (chest, relaxed arm, contracted arm, forearm, wrist, waist, abdominal, hip, proximal thigh, and calf), and breadths (biacromial, biiliac, chest, elbow, bitrochanteric, wrist, knee, and bimalleolar) were measured by conventional procedures stated in the literature [15, 16] using Sanny scientific equipment.

(2) *Maturation.* For determining the biological development, the maturity offset was predicted by gender-specific regression equations based upon noninvasive techniques, using chronological age, height, body mass, sitting height, and leg length measurements [17]. The method predicts years from peak height velocity (PHV) according to the Mirwald et al. [17] equation for boys:

$$\begin{aligned} \mathrm{PHV} = & -9.236 + 0.0002708\,(\mathrm{Lh} \times \mathrm{Sh}) - 0.001663\,(\mathrm{A} \times \mathrm{Lh}) \\ & + 0.007216\,(\mathrm{A} \times \mathrm{Sh}) + 0.02292\,(\mathrm{Wt}/\mathrm{Ht} \times 100)\,, \end{aligned} \tag{1}$$

where Lh stands for legs height (cm), Sh for seating height (cm), A for age (years), Wt for body weight (kg), and Ht for height (cm).

(3) *Chronological Age.* Chronological ages were based on birth year and grouped in decimal values adjusted to the nearest integer.

To ensure the precision of the results, intra evaluator technical errors of measurement absolute (TEM) and relative (TEM%) were calculated (Table 1). In subsequent days, duplicates for all measures were applied in thirteen subjects, when

Table 1: Descriptive statistics of body composition in boys ($n = 408$), including absolute and relative TEM of the dependent (DXA) and independent measures (maturation, body size, and skinfolds).

	Range	Mean	SD	TEM	TEM%	CI 95%
DXA						
Fat mass (kg)	1.3–41.8	9.3	7.5	0.22	1.42	8.6–10.0
Bone mineral content (kg)	0.7–4.1	2.1	0.8	0.01	0.03	2.1–2.2
Lean mass tissue (kg)	17.1–72.6	38.1	12.7	0.06	0.15	36.9–39.4
Age/maturation/anthropometrics						
Age (year)	8–18	13.7	2.99	—	—	12.9–13.5
PHV (year)	−4.7–4.5	−0.5	2.5	—	—	−0.8–0.3
Seating height (cm)	61.5–99.5	82.3	8.8	0.26	0.30	81.4–83.1
Height (cm)	120.3–196.8	158.1	17.7	0.17	0.11	156.4–159.8
Weight (kg)	20.6–119.4	50.2	17.4	0.27	0.29	48.5–51.9
Suprailiac skinfold (mm)	2.8–64.5	13.3	10.2	0.35	2.27	12.4–14.3
Horizontal abdominal skinfold (mm)	1.5–66.0	16.5	12.0	1.59	4.96	15.4–17.7

TEM: absolute technical error of measurement; TEM%: relative technical error of measurement; CI: confidence interval; DXA: dual-energy X-ray absorptiometry; PHV: years for peak height velocity.

the results were always within the expected tolerance limits [15].

2.3. Statistical Analysis. The SPSS Statistics, version 13, for Windows (SPSS Inc., Chicago, IL) was used to analyze the data of descriptive statistics (mean, standard deviation, range, technical error of measure relative, absolute, and the confidence interval—CI 95%) were used to describe the sample, and correlation coefficient was applied to verify the basic assumption of the relations between dependent and independent variables. For developing the multicomponent anthropometric equation, a multivariate regression model ($_nY_m = {}_nX_{(r+1)(r+1)}\beta_m + {}_n\varepsilon_m$) was utilized as diagonal mutual analysis, parameter estimation, and the least squares errors method by R-Free Software [18]. When the choice of remaining variables the following criteria were used (a) maintenance of a high correlation between independent and dependent variables, (b) uniformity of the data, (c) centralized distribution of the residuals, (e) reducing the number of independent variables while maintaining the highest levels of significance after stepwise, with adjustments by the Pillai approach to test the F values, (f) multicollinearity tolerated, (g) determining the β values in a multivariate model, and (h) remaining of the high precision and validity of the final model. More explanations of the multivariate analysis are given by Johnson and Wichern [19].

For performing the validation of the models we used thePRESS statistic [20]. From the deletion of an observation, proposed equations with the remaining sample are conducted, and the process is repeated. The PRESS statistic is defined as the sum of squares of residuals (PRESS) in:

$$\text{PRESS} = \sum_{i=1}^{n} \left[y_i - \hat{y}_{(i)} \right]^2. \quad (2)$$

Thus, a model with a high degree of predictability for excluded observations gives the value of the R^2_{PRESS} (close to 1) and a standard estimated error ($\text{SEE}_{\text{PRESS}}$) near zero. In summary, the PRESS statistic gives an indication of the predictive ability of the regression model. The validation procedure that uses PRESS is similar to the application of the equation to an independent sample [21].

3. Results

Characteristics of the total sample are shown in Table 1, including range (minimum–maximum), TEM, TEM%, and confidence interval (95%).

Table 2 presents the correlation matrix within some of the 32 independents, including size measures, skinfolds, circumferences, breadths, and maturation by PHV with and the dependent variables.

A centered distribution of the residuals (differences) was observed for the response components (Figure 1).

From all 32 initial variables used as predictors of the dependent variables, a stepwise regression was performed individually for FM, BMC, and LST in order to select the common variables for all three components, with the higher significance level. The number of predictor variables was reduced after 27 eliminations, and a final model was obtained with five independent variables and high precision (R^2), meaning that the models largely explained the variance of the dependent variables (Table 3). Here, the Pillai method approach was used to test the F values. The estimated parameters vector (β) of the model was obtained for each variable, resulting in a single model for all dependent variables (Table 3).

From the multivariate parameters, it was possible to predict simultaneously each body component (FM, BMC, and LST), considering the interrelationship of dependent variables, unlike the traditional methods (one-dimensional analysis). Multicollinearity within the final independent variables was tested, and cases were found in which the variables were highly collinear. In those cases, an independent variable in the model was eliminated and performed the ratio between the largest and the lowest eigenvalues [20], until resulting in

Table 2: Correlation matrix between independent and dependent variables in the pediatric population.

	Independent												Dependent		
	Wt	SkTr	SkSi	SkHab	SkTh	CiAr	CiWs	CiTh	BrEl	BrKn	PHV	Age	FM (kg)	BMC (kg)	LST (kg)
Ht	0.84	−0.13	0.12	0.11	−0.14	0.67	0.65	0.69	0.85	0.70	0.94	0.88	0.28	0.91	0.95
Wt		0.29	0.54	0.52	0.27	0.91	0.89	0.89	0.87	0.77	0.87	0.78	0.70	0.92	0.91
SkTr			0.85	0.86	0.89	0.44	0.46	0.37	0.11	0.23	−0.09	−0.17	0.82	−0.02	−0.10
SkSi				0.90	0.80	0.65	0.68	0.54	0.34	0.38	0.17	0.08	0.92	0.24	0.17
SkHab					0.83	0.62	0.66	0.56	0.31	0.35	0.15	0.05	0.92	0.22	0.14
SkTh						0.41	0.45	0.38	0.09	0.19	−0.09	−0.16	0.80	−0.02	−0.11
CiRa							0.89	0.86	0.77	0.67	0.74	0.66	0.75	0.77	0.76
CiWa								0.83	0.75	0.69	0.70	0.61	0.78	0.74	0.72
CiTh									0.76	0.71	0.74	0.65	0.69	0.79	0.77
BrEl										0.79	0.82	0.75	0.46	0.84	0.87
BrKn											0.67	0.60	0.50	0.73	0.72
PHV												0.97	0.32	0.93	0.95
Age													0.22	0.87	0.89

Ht: height; Wt: weight; Sk: skinfold; SkTr: triceps; SkSi: suprailiac; SkHab: horizontal abdominal; SkTh: mid-thigh; Ci: circumference; CiRa: relaxed arm; CiWa: waist; CiTh: proximal thigh; Br: breadth; BrEl: elbow; BrKn: knee; PHV: years for peak height velocity; FM: fat mass, BMC: bone mineral content; LST: lean soft-tissue.

Table 3: Multicomponent anthropometric model matrix, precision, and internal cross-validity for simultaneously measuring of body composition in boys.

	β FM	β BMC	β LST
Height (cm)	−0.0857	0.0032	0.0820
Weight (kg)	0.3139	0.0392	0.6419
SkSi (mm)	0.1970	−0.0095	−0.1964
SkHab (mm)	0.2350	−0.0105	−0.2321
PHV (yr)	−0.6571	0.0525	0.7047
Precision			
R^2	0.9808	0.9930	0.9981
Adj R^2	0.9805	0.9929	0.9981
$SEE_{residual}$ (kg)	1.6660	0.1923	1.7480
Cross-validation			
PRESS	1162.433	15.37255	1280.083
R^2_{PRESS}	0.9490	0.9402	0.9804
SEE_{PRESS} (kg)	0.0850	0.0098	0.0892

β: estimated parameter vector; FM: fat mass, BMC: bone mineral content; LST: lean soft tissue; Sk: skinfold; SkSi: suprailiac; SkHab: horizontal abdominal; PHV: age for peak height velocity; R^2: coefficient of determination (observed and cross-predicted); Adj R^2: adjusted coefficient of determination; $SEE_{residual}$: residual standard error of estimate; PRESS: sum of squares of residuals; R^2_{PRESS}: press coefficient of determination; SEE_{PRESS}: press standard error of estimate.

a final product with only moderate multicollinearity (λ = 167.0637).

Table 4 summarizes mean values and standard deviations for the descriptive characteristics obtained from the DXA scan by age group. The FM showed increases up to the age of 13, which tend to stabilize. However, there were no statistically significant age differences. All other significant differences for subsequent ages in BMC were found from 11- to 12-year-old age group (P = 0.021), from 13- to 14-year-old age group (P = 0.001), and from 14- to 15-year-old age group (P = 0.001); for LST, the differences were found from 11- to 12-year-old age group (P = 0.001), from 13- to 14-year-old age group (P = 0.001), and from 14- to 15-year-old age group (P = 0.001).

3.1. The Precision of the Model. The correlations between the predicted values (of the model) and those observed (by DXA) in FM, BMC, and LST (Figure 2) showed an increased dispersion at higher scores of body composition.

The PRESS related statistics (R^2), adjusted coefficients of determination (Adj R^2), and standard error of estimate ($SEE_{RESIDUAL}$) for residual analysis are showed in Table 3.

3.2. Cross-Validation. In this study, the error was determined by the outcome of Y-observed minus Y-estimated. Parameters of internal validation included R^2_{PRESS} statistic and SEE_{PRESS}, as observed in Table 3. The model is valid according

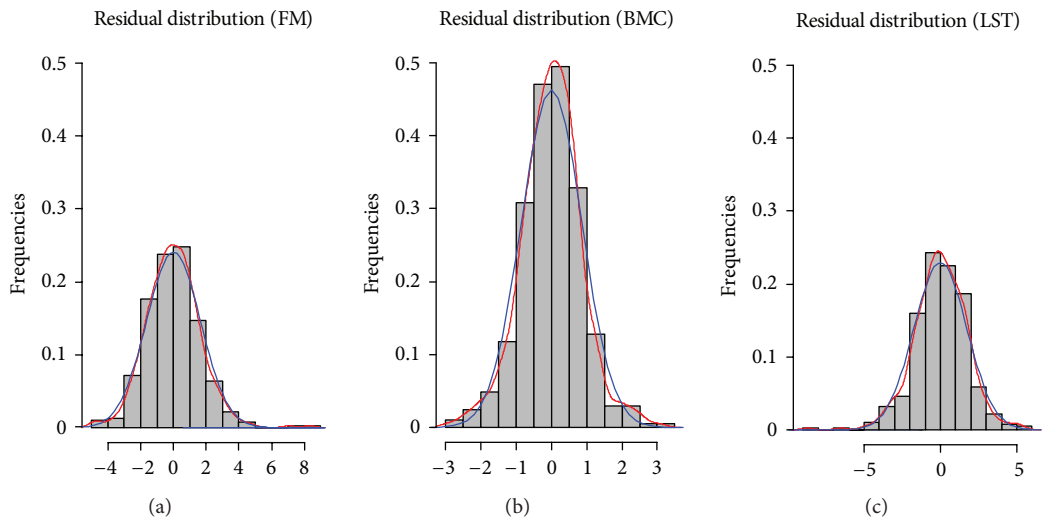

Figure 1: Multivariate distribution of residuals for fat mass (FM), bone mineral content (BMC), and lean soft tissue (LST).

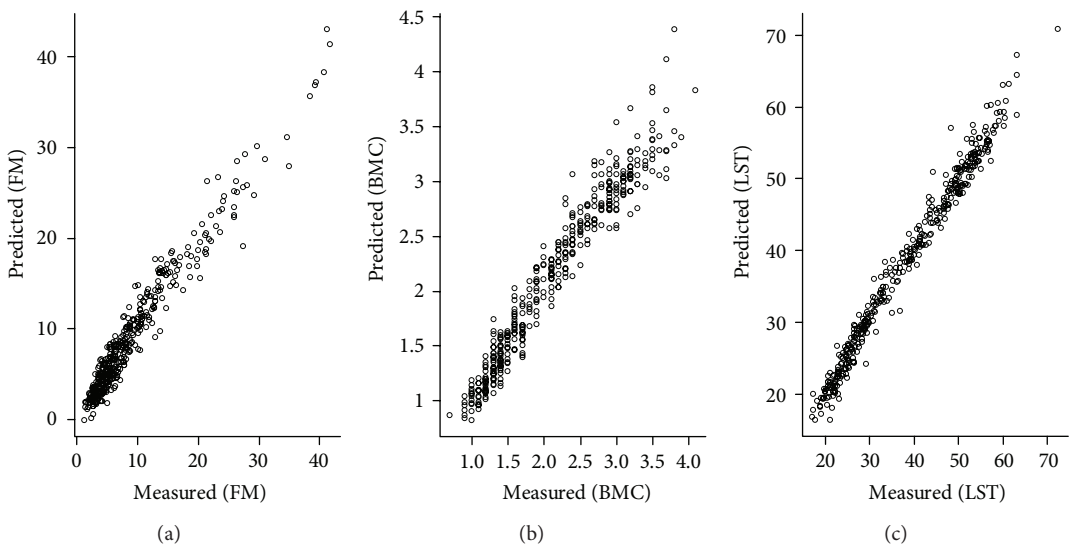

Figure 2: Scatterplot of predicted and actual fat mass (FM), bone mineral content (BMC), and lean soft tissue (LST) values in the male pediatric population.

to the assumptions defined in the methodology, where R^2_{PRESS} should be close to "1" and $\text{SEE}_{\text{PRESS}}$ near "0".

Then, the final model for each dependent variable could be expressed as

$$\begin{aligned}
\text{FM} &= -\,0.0857\ \text{Height} + 0.3139\ \text{weight} \\
&\quad + 0.1970\ \text{SkSi} + 0.2350\ \text{SkHab} - 0.6571\ \text{PHV}, \\
\text{BMC} &= 0.0032\ \text{Height} + 0.0392\ \text{weight} \\
&\quad - 0.0095\ \text{SkSi} - 0.0105\ \text{SkHab} + 0.0525\ \text{PHV}, \\
\text{LST} &= 0.0820\ \text{Height} + 0.6419\ \text{weight} \\
&\quad - 0.1964\ \text{SkSi} - 0.2321\ \text{SkHab} + 0.7047\ \text{PHV},
\end{aligned} \tag{3}$$

where SkSi stands for suprailiac skinfold (mm), SkHab for horizontal abdominal skinfold (mm), and PHV for peak height velocity (years).

4. Discussion

The multicomponent model approach presented in this study showed a high correlation in most comparisons between independent and dependent variables (Table 2), suggesting the possibility of using these variables as an alternative method.

The multicomponent determination of body composition during growth finds application in field and clinical settings allowing specific definition for the component of interest. In sports, for example, monitoring the training process to

Table 4: Mean and standard deviation of DXA dependent variables by age group.

Age (years)	FM	BMC	LST
8 (n = 28)	6.1 ± 4.4	1.2 ± 0.2	22.0 ± 2.7
9 (n = 32)	6.6 ± 4.2	1.2 ± 0.2	23.3 ± 3.0
10 (n = 34)	7.0 ± 4.5	1.3 ± 0.2	24.5 ± 3.3
11 (n = 40)	7.8 ± 6.2	1.5 ± 0.3*	26.5 ± 3.8*
12 (n = 37)	8.4 ± 6.5	1.8 ± 0.3	32.3 ± 5.3
13 (n = 39)	10.9 ± 9.5	2.0 ± 0.4*	36.2 ± 6.3*
14 (n = 47)	10.3 ± 9.4	2.3 ± 0.5*	42.4 ± 7.1*
15 (n = 42)	11.1 ± 8.1	2.7 ± 0.5	48.4 ± 6.8
16 (n = 39)	10.3 ± 5.5	3.0 ± 0.4	50.6 ± 5.0
17 (n = 40)	11.9 ± 8.7	3.0 ± 0.4	52.0 ± 6.0
18 (n = 30)	10.1 ± 8.7	3.1 ± 0.8	53.8 ± 5.9

DXA: dual-energy X-ray absorptiometry; FM: fat mass; BMC: bone mineral content; LST: lean soft tissue. *Subsequent age significantly different at $P < 0.05$.

reduce FM or increase lean mass may be of interest to technicians, aiming to improve sports performance. For most cases, the uncertainty of which component has contributed to an increase in body weight may compromise an adequate decision for exercise prescription, since the true relationships between FM and FFM are not known. Therefore, an accurate and precise body composition estimation is required using simple methods [1].

In the present study, the greater associations of FM were observed with skinfolds, BMC, with growth components (height, weight, breadth, and PVC) and LST with growth components and circumferences (Table 2), expressing the real expected relationships between the types of measurements and the components measured in a combined prediction. This is a crucial fact to determine the robustness of the model [19]. This is so because the combined estimation of the parameters produces zero restrictions on coefficients of other equations [22]. The relationship between the predictors and the response variables must be strong.

However, the robustness of the model can be compromised if there is multicollinearity between independent variables. The multicollinearity was examined, given the natural relationships between the independent variables. Therefore, the elimination of independent variables was required, and those who are not commonly used in the literature or without a high predictive significance were removed. Apart from being a practical model, the least number of possible variables should be considered. In this case, the estimates of regression coefficients become very sensitive to small changes in the planning matrix. The variations of the estimators are high, making testing of H_0: $\beta_j = 0$ versus H_A: $\beta_j \neq 0$ diff $= 0$; therefore, important independent variables could mistakenly be removed. One of the assumptions of the linear model is that the rank of the matrix $(X'X)$ is equal to $k + 1$. Thus, in addition to moderate multicollinearity ($\lambda = 167.0637$) and near the bottom of this classification (from 100 to 1000) [23] and the determinant away from zero, the rank axis of $X'X$ matrix is complete. Then, there is its classical inverse $(X'X)^{-1}$ [det $(X'X) \neq 0$], multiplied by the right side of the normal equation system, allowing the β obtaining the least squares estimator. The classical inverse matrix procedure was calculated, resulting in the root close to the efficiency characteristic, once the issue of moderate multicollinearity was observed, near to lower limit. The gain in predictive efficiency in the use of multivariate analysis in relation to various regressions is well proven. Basically, this is true because the efficiency jointly estimates the parameters and produces zero restrictions on coefficients of other equations [20], with the same error as vectors of estimated betas, enhancing the prediction.

So far, only the FM has been predicted by pediatric anthropometric models, determined by anthropometric-based models which have been developed against densitometric techniques in children [2, 3, 24–26] showing relatively low ability in predicting the variability of the reference method ($R^2 < 0.80$) when compared to those developed from the present study (Table 3). However, investigations can be controversial when very young or very obese children are involved in the observations [27], and the literature expresses caution in the estimation of body composition when BMI is high [1, 28, 29]. The model proposed in this study was able to predict the body composition also of overweight subjects according to the Cole et al. [30] cutoff points (11 cases). Even if these cases were removed, the accuracy of the model remained similar, confirming a possible generalization of the predictive equations for assessing overweight children.

The method of internal validity adopted [20] confirmed the effectiveness of the model to predict the components of body composition with a high internal validity (R^2_{PRESS} = 0.94 to 0.98) and low proportional errors of estimation ($\text{SEE}_{\text{PRESS}}$ = 0.01 to 0.09), that is, a score $R^2_{\text{PRESS}} = 0.9490$ for FM (Table 3) may explain about 94.90% of the variability in predicting new observations in independent samples, compared with about 98.08% of variability in the original data, explained by the least squares (R^2) method. Also, the high independent R^2_{PRESS} (94.02% and 98.04%), respectively, for BMC and LST indicates the strength of the model in predicting the lean body composition of young males between 8 and 18 years of age. These results provide the generalizability of the model, even when the variance of body composition is high. The low dispersion of the measured and predicted values for the body components (Figure 2) seems to confirm this hypothesis.

To facilitate a better understanding of the practical utility of the model, we show the following example for predicting FM, BMC, and LST in a 13-year old boy (Table 5). After obtaining, the measures (independent variables) of height, weight, maturation (PHV), and skinfolds (suprailiac and horizontal abdominal) simply apply the anthropometric multicomponent matrix described in Table 3.

The products of each measure, multiplied by its β coefficient regression, result in absolute values (kg) for FM, BMC, and LST.

A limitation of this study is that although DXA was used as a reference method to develop our model, this technique is not considered the gold standard for pediatric

Table 5: A worked example for predicting fat mass (FM), bone mineral content (BMC), and lean soft tissue (LST) for a boy.

Variables	Measures	FM	Product	BMC	Product	LST	Product
Height (cm)	*148.3*	**−0.0857**	*−12.71*	**0.0032**	*0.48*	**0.0820**	*12.16*
Weight (kg)	*40.0*	**0.3139**	*12.56*	**0.0392**	*1.57*	**0.6419**	*25.68*
Skinfolds (mm)							
Sk suprailiac	*18.7*	**0.1970**	*3.68*	**−0.0095**	*−0.18*	**−0.1964**	*−3.67*
Sk horiz. abdom	*20.0*	**0.2350**	*4.70*	**−0.0105**	*−0.21*	**−0.2321**	*−4.64*
Maturation (years)							
PHV	*−1.6*	**−0.6571**	*1.05*	**0.0525**	*−0.08*	**0.7047**	*−1.13*
Total (kg)		Sum (FM) = 9.28		Sum (BMC) = 1.57		Sum (LST) = 28.40	

FM: fat mass, BMC: bone mineral content; LST: lean soft tissue; Sk: skinfold; PHV: age for peak height velocity. Against original values measured by DXA (FM = 9.30; BMC = 1.50; LST = 28.50).

populations. A four-compartment model (4C model) is actually the most strong model for accurately assesses body composition in children as it accounts for the variability of the main FFM components [31]. Though its use is recommended as criterion, this method is time-consuming and requires sophisticated equipment, specialized technicians, and high costs which make it difficult for use in large samples [32]. In addition, the 4C model is not free of errors, considering the number of required techniques necessary for determining the main FFM constituents (water and mineral) [8]. Therefore, the use of DXA is an alternative chosen by several investigators to develop predictive equations for children and adolescents [25, 33–38]. In fact, a recent study revealed DXA as a precise and valid method for body composition assessment [39]. Another limitation that needs to be addressed is the ethnical differences of this sample, who could limit the generalization of the equations to other populations. Therefore, further studies are recommended that examine the accuracy of the models before its application.

Concluding, new anthropometric-based model for assessing body composition of children and adolescent males was proposed. Considering the unavailability of sophisticated instruments in field and clinical settings, these models proved to be a valid and alternative solution to estimate body composition in a male pediatric population.

Conflict of Interests

The authors declare no conflict of interests. See the online ICMJE Conflict of Interests Forms for this paper.

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