Nutrition 30 (2014) 305–312

Contents lists available at ScienceDirect

Nutrition

journal homepage: www.nutritionjrnl.com

Applied nutritional investigation

The four-compartment model of body composition in obese Chilean schoolchildren, by pubertal stage: Comparison with simpler models

Fabian Vasquez Vergara Ph.D. [a,*], Erik Diaz Bustos Ph.D. [b], Lydia Lera Marques Ph.D. [b], Loretta Vasquez Flores Ph.D. [b], Alyerina Anziani Gonzalez B.Sc. [b], Raquel Burrows Argote M.D. [b]

[a] School of Nutrition and Dietetics, Faculty of Medicine, University of Chile, Santiago, Chile
[b] Institute of Nutrition and Food Technology, University of Chile, Santiago, Chile

ARTICLE INFO

Article history:
Received 11 March 2013
Accepted 7 September 2013

Keywords:
Body fat
Fat-free mass
Four-compartment model
Isotopic dilution
Radiographic absorptiometry
Plethysmography
Anthropometric equations

ABSTRACT

Objectives: We assessed the agreement of body fat and fat-free mass measured by simpler methods against the four-compartment model (4C).
Methods: In 60 obese schoolchildren (body mass index ≥95th percentile) between the ages of 8 and 13 y who were recruited from one school in Chile, multicompartmental body composition was estimated with the use of isotopic dilution, plethysmography (BodPod), radiographic absorptiometry (DEXA), and anthropometric equations. These results were compared to those of the 4C model, which is considered the gold standard.
Results: For body fat, the 4C model showed the best agreement with DEXA for boys in Tanner stages I and II ($r = 0.971$) and with isotopic dilution for boys in Tanner stages III and IV ($r = 0.984$). The best agreement in girls occurred with isotopic dilution, regardless of pubertal stage ($r = 0.948$ for Tanner stages I and II; $r = 0.978$ for Tanner stages III and IV). Both isotopic dilution and the Huang, Ellis, and Deurenberg anthropometric equations underestimated body fat in boys; by contrast, DEXA, BodPod, and the Slaughter equation overestimated body fat in boys. All of the equations underestimated body fat in girls. For fat-free mass in both boys and girls, the 4C model showed the best agreement with isotopic dilution, regardless of pubertal stage. The Huang equation showed the best agreement for boys ($r = 0.730$ for Tanner stages I and II; $r = 0.695$ for Tanner stages III and IV) and for girls in Tanner stages I and II ($r = 0.884$). The Ellis equation had the best agreement for girls in Tanner stages III and IV ($r = 0.917$).
Conclusions: For obese Chilean children of both sexes, isotopic dilution and DEXA were the two-compartment methods that had the best agreement with the gold-standard 4C model for both body fat and fat-free mass; these were followed by the Huang and Ellis anthropometric equations.

Introduction

In Chile, the prevalence of childhood obesity has climbed to 23.1%, and metabolic syndrome affects 25% to 35% of obese Chilean schoolchildren (body mass index ≥ 95th percentile) [1, 2]. Scientific evidence suggests that increased body fat (BF)—especially if it is distributed in the abdominal area—is an early risk factor for cardiovascular disease. Increased BF also correlates directly with disorders related to heart disease, including the magnitude and prevalence of insulin resistance, dyslipidemia, systemic inflammation, type 2 diabetes mellitus, high blood pressure, heart attack, and premature death [3–7]. Therefore, improving pediatric BF assessment in terms of both improving the accuracy of the measurement and having a better understanding of its relationship with cardiometabolic disorders is an important objective for both scientific research and clinical practice [8–10].

Nutritional status assessment is usually based on a global indicator that obscures the underlying body composition, such as

F.V. initiated the study, participated in data collection, obtained the data set that was interpreted, and wrote the manuscript. E.D., L.V., and A.A. participated in data collection. L.L. assisted with the interpretation of results. R.B. assisted with interpretation and the writing of the manuscript.

* Corresponding author. Tel.: +56-2-2978-6754; fax: +56-2-2978-6182.
E-mail address: fvasquez@med.uchile.cl (F. Vasquez Vergara).

0899-9007/$ - see front matter © 2014 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.nut.2013.09.002

the BF and fat-free mass (FFM) percentages. Childhood obesity is defined with the use of the body mass index formula, which measures weight in relation to height [11,12]. This indicator is the most widely applied formula for using weight to predict health risk, but it has significant limitations, including the failure to distinguish between BF and FFM [13]. Because obesity-related health risks are attributable to BF rather than FFM, various alternative methods have been proposed to quantify risk [3], such as the following: waist circumference and waist-to-hip ratio [14]; upper arm length and sitting height [15] or knee height [16] in relation to weight; waist-to-height ratio [17]; a body adiposity index [18]; an index of central obesity [19]; maternal body size [20]; bioimpedance spectroscopy [21]; and estimates of the percentage of body fat (%BF) [22]. This last measure, %BF, seems to provide the most accurate and predictive measure of BF and its associated health risks; however, the methods used to measure %BF are costly, sophisticated, or invasive, thereby making the measure difficult to apply to large population samples [13,23,24]. One alternative is to estimate body composition with the use of anthropometric techniques, in which body measurements are used as inputs for equations that predict BF and FFM. This method is simple, inexpensive, and easy to apply in a pediatric population. Therefore, it would be useful to determine how well these equations approximate the gold standard [25]. Most evaluations of pediatric body composition are based on Siri's two-compartment (2C) model [26], which has been shown to overestimate %BF. This discrepancy is attributable to the chemical immaturity of children. Because children have a higher proportion of water and a lower proportion of minerals and proteins, they have a lower density of FFM as compared with adults [27]. To improve the accuracy of such estimates, more precise methods have been developed, such as multiple-compartment models to estimate BF and FFM in children and adolescents [28]. The 4C model divides the body into constituent fractions of fat, water, minerals, and protein. This 4C model is considered the gold standard for determining body composition in adults [29], but it has not been widely validated in children and adolescents [27]. Therefore, the aim of this study was to assess the agreement of BF and FFM measures obtained by simpler models (e.g., the 2C model, anthropometric equations) with those obtained by the four-compartment (4C) model in obese schoolchildren.

Materials and methods

Subjects

The subjects were 60 obese schoolchildren between the ages of 8 and 13 y (13 boys and 27 girls) who were recruited from an elementary school in the commune of Macul in Santiago, Chile. The study group was a convenience sample that was chosen based on the school's proximity to the measurement center. The inclusion criteria were a body mass index at the 95th percentile or greater according to the Centers for Disease Control and Prevention National Center for Health Statistics reference standards [30], full-day school enrollment, the consent of the parents, and the assent of the children. The exclusion criteria were diagnosis with a psychomotor disorder or the use of medications that affect body composition, physical activity, dietary intake, or biochemical parameters. The study was approved by the Ethics Committee of the University of Chile.

Biological age

Pubertal development was classified by Tanner stage in accordance with female breast development and male genital development [31]. Tanner stage was evaluated by visual inspection during the physical examination, which was performed by the study's pediatrician.

Anthropometry

Fasting weight and height were measured in the early morning. The children wore underwear only and stood on the scale with their feet near the center, their arms at their sides, and their heads in a neutral position so that the line from the corner of the eye to the origin of the ear was parallel with the floor. Weight was measured using an electronic precision scale (SECA® Model 767) with a sensitivity of 10 grams. Height was measured using a Holtain stadiometer (SECA) with a sensitivity of 0.1 cm. Both values were imported via a Precision Hispana touch screen. Four skinfold measurements were obtained in triplicate (i.e., biceps, triceps, subscapular, and suprailiac) with the use of a Lange caliper with millimetric precision (1 mm) using the technique described by Lohman and colleagues [32].

Anthropometric equations

The following anthropometric equations were performed:

a) *Slaughter* [33]. %BF is estimated on the basis of the triceps and subscapular skinfolds and by sex, pubertal stage, and race.

Girls:
$\%BF = 1.33 \times (\text{Triceps} + \text{Subscapular}) – 0.013 \times (\text{Triceps} + \text{Subscapular})^2 – 2.5$
Prepubescent boys:
$\%BF = 1.2 \times (\text{Triceps} + \text{Subscapular}) – 0.008 \times (\text{Triceps} + \text{Subscapular})^2 – 1.7$
Pubescent boys:
$\%BF = 1.2 \times (\text{Triceps} + \text{Subscapular}) – 0.008 \times (\text{Triceps} + \text{Subscapular})^2 – 3.4$
Postpubescent boys:
$\%BF = 1.2 \times (\text{Triceps} + \text{Subscapular}) – 0.008 \times (\text{Triceps} + \text{Subscapular})^2 – 5.5$

If the sum of the measures of the triceps and subscapular folds is greater than 35 mm, then the following equations are used:

Girls:
$\%BF = 0.546 \times (\text{Triceps} + \text{Subscapular}) + 9.7$
Boys:
$\%BF = 0.783 \times (\text{Triceps} + \text{Subscapular}) + 1.6$

b) *Ellis* [34,35]. BF in kg is estimated on the basis of height and weight and by race and sex.

Hispanic girls:
$BF\ (kg) = 0.677 \times \text{Weight (kg)} – 0.217 \times \text{Height (cm)} + 15.5$
Hispanic boys:
$BF\ (kg) = 0.591 \times \text{Weight (kg)} – 1.82 \times \text{Age (y)} + 3.36$

c) *Deurenberg* [36]. %BF is estimated on the basis of body density (BD), which in turn is estimated on the basis of four skinfold measures (i.e., biceps, triceps, subscapular, and suprailiac) and by pubertal stage.

$\%BF = (562 – 4.2) \times (\text{Age [y]} - 2) - (525 - 4.7) \times (\text{Age [y]} - 2) / BC\ (kg/L)$

BD is calculated on the basis of the following equations:

Prepubescent girls:
$BD\ (kg/L) = 1.1187 – 0.0630 \times \log(\sum 4\ \text{Skinfolds}) + 1.9 \times (\text{Age [y]} \times 10^{-3})$
Pubescent girls:
$BD\ (kg/L) = 1.1074 – 0.0504 \times \log(\sum 4\ \text{Skinfolds}) + 1.6 \times (\text{Age [y]} \times 10^{-3})$
Postpubescent girls:
$BD\ (kg/L) = 1.1830 - 0.0813 \times \log(\sum 4\ \text{Skinfolds})$
Prepubescent boys:
$BD\ (kg/L) = 1.1133 - 0.0561 \times \log(\sum 4\ \text{Skinfolds}) + 1.7 \times (\text{Age [y]} \times 10^{-3})$
Pubescent boys:
$BD\ (kg/L) = 1.0555 – 0.0352 \times \log(\sum 4\ \text{Skinfolds}) + 3.8 \times (\text{Age [y]} \times 10^{-3})$
Postpubescent boys:
$BD\ (kg/L) = 1.1324 – 0.0429 \times \log(\sum 4\ \text{Skinfolds})$

d) *Huang* [37]. BF in kg is estimated on the basis of weight, age, and sex (girls = 0, boys = 1).

$BF\ (kg) = 0.632 \times \text{Weight (kg)} – 1.606 \times \text{Age (y)} – 1.882 \times \text{Sex} + 3.330$

Isotopic dilution

Total body water was measured via deuterium dilution. The isotope was administered orally at a dose of 4 grams of deuterium oxide (99.8%) in accordance with the subject's body weight. Body water values were derived from deuterium oxide concentrations according to the plateau method. Subjects fasted for a 3-h equilibration period to minimize changes in total body water content [38]. A baseline saliva sample of approximately 2 mL was taken, and then the dose of deuterium was given along with 20 mL of water. The post-dose saliva sample was