

The use of body mass index for measurement of fat mass in children is highly dependant on abdominal fat

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الخلاصة: درس الباحثون العلاقة بين سهم الجسم ونسبة كتلة الجسم لدى أطفال بدینين من سكان ينتهيون إلى أعراق متعددة. وقارنوا أحراز - Z لكتلة الجسم بالقياس المزدوج لامتصاص الأشعة السينية للتعرف على تركيب كامل الجسم وعلى توزيع الشحم في مختلف أجزائه. واتضح أن أفضل معادلة للتعرف على نسبة كتلة الجسم هي تقسيم الرقم 1 على $[0.159 - 0.013 \times \text{الشريحة المثلوية لمجمل شحم البطن}] - (0.01 \times \text{حرز Z لكتلة الجسم})$; حيث تتراوح قيمة الشريحة المثلوية لشحم البطن بين 1 و5. وقد اتضح وجود توافق مرتفع لنسبة كتلة الجسم المتوقع مع نسبة كتلة الجسم بالقياس المزدوج لامتصاص الأشعة السينية، ولم تكن هناك فروق يمكن كشفها في هذه العلاقة بين المجموعات العرقية (الإثنية) المختلفة. وينبغي أن يستخدم كل من نسبة كتلة الجسم وشحم البطن كعوامل تقريبية وسليمة لتحديد مدى الشحامة.

ABSTRACT We examined the relationship between body fat and body mass index (BMI) in a multiethnic population of obese children. BMI z-scores were compared to DEXA measures of whole body composition and regional fat distribution. Fat mass index (FMI) was best predicted by the equation: $1/[0.159 - 0.013 \times \text{percentile of total abdominal fat}] - (0.01 \times \text{BMI z-score})$, where percentile of abdominal fat ranges from 1 to 5. Predicted FMI had high agreement with FMI measured by DEXA. There were no detectable differences in this relation between different ethnic groups. Both BMI and abdominal fat should be used as a proxy to determine adiposity.

L'IMC comme mesure de la masse graisseuse chez l'enfant est très lié à la quantité de graisse abdominale

RÉSUMÉ Nous avons examiné la relation entre la masse graisseuse et l'indice de masse corporelle (IMC) dans une population multiethnique d'enfants obèses. Les scores Z d'IMC ont été comparés aux mesures DEXA relatives à la composition de l'ensemble du corps et à la répartition des graisses dans les différentes régions de l'organisme. La meilleure prédiction de l'indice de masse graisseuse (IMG) était obtenue grâce à l'équation : $1/[0,159 - 0,013 \times \text{percentile de la graisse abdominale totale}] - (0,01 \times \text{score Z d'IMC})$, la graisse abdominale étant quantifiée de 1 à 5. On observait une grande concordance entre les prévisions relatives à l'IMG et la mesure de cet indice par la méthode DEXA. Il n'existe pas dans ce rapport de différence détectable entre les groupes ethniques. L'IMC et la graisse abdominale devraient être utilisés comme indicateurs indirects pour déterminer l'adiposité.

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Introduction

Obesity is a leading underlying cause of morbidity and mortality worldwide. Its prevalence in many developing countries such as in North Africa, the Gulf region, Latin America and the Caribbean is even higher than in some of the industrialized nations [1,2]. The basic process in obesity is the accumulation of excess fat in the body to the extent that health is adversely affected. The diagnosis should ideally be based on the accurate measurement of this amount of excessive fat. Different techniques are used for that purpose. Examples include underwater weighing, total body water, total body electrical conductivity, total body potassium, computed tomography, magnetic resonance, and dual energy X-ray absorptiometry (DEXA). Because of complexity, skills required and cost, the use of these methods is limited to research and validation studies in referral settings as standard methods [3]. In practice, in adults as well as in children, we rely on anthropometric measures such as body mass index (BMI) [4–6]. Reference ranges of BMI for children of predominantly Caucasian populations have been published in a number of countries [4,7,8]. In addition to simplicity, the advantages of BMI include its wide usage across disciplines ranging from international surveillance to individual patient assessment. However, BMI is only a surrogate measure of body fat as it is a ratio of total body weight, not only body fat, to the square of height.

In comparative studies of BMI with standard techniques such as DEXA, the correlation varies from weak to very strong [9,10]. Most validation studies have been conducted in Caucasians in North America and Europe. Ethnic comparisons have been made with African-American and Hispanic groups. Other studies have involved Indonesians, Sri Lankans, Chinese and other

Asians [11–13]. The application of formulas established on 1 population may produce biased estimates when applied to another race. Ethnic- or population-specific predictive equations have to be developed for the assessment of body composition, especially in a multicultural society [12,13].

The interpretation of BMI as a measure of fatness in groups of children and adolescents should be cautious across sex, age, height, muscularity and race groups [10,14,15]. To the best of our knowledge, no study has looked specifically at ethnic groups from North Africa. In addition, in most validation studies, the role of regional body fat distribution [14], the accuracy of BMI in individual obese children [14,16], the use of standard techniques for measuring agreement between different methods [17] and multiple regression were not all looked for simultaneously in the same study.

Our aim was to examine the relationship between BMI and body fat as measured by DEXA in a multiethnic population of obese children that also included children of North African origin.

Methods

Design

We performed a retrospective study based on records from the hospital-based childhood obesity management unit of the Department of Paediatric Gastroenterology and Nutrition of the Hôpital Necker Enfants malades in Paris, France. This specialized unit serves obese children from a multiethnic population in one of the areas with the highest prevalent of obesity in France. The unit is equipped with facilities for sophisticated investigations such as DEXA for body compartment measurements (Hologic Corporation, Waltham, United States of America).

Subjects

Children included in the study were all obese children who attended day care in the unit during the period 1999–2006, and for whom different DEXA measures on body and regional composition were available.

Measures

BMI *z*-scores were determined using the LMS method for constructing normalized growth standards [18] and referred to French growth curves [4].

DEXA was used to assess composition and regional distribution of body fat. Each subject's body was scanned by DEXA. Whole body fatness was based on the DEXA total body fat (TBF). Whole body fat was adjusted for weight (DEXA percentage body fat, PBF) which was defined as $100 \times \text{fat mass}/\text{body weight}$. It was also adjusted for height (DEXA fat mass index, FMI) defined as TBF/height². Regional distribution of fat in the abdomen was expressed as DEXA total abdominal fat (TAF), and was also adjusted for weight (DEXA percentage of abdominal fat, PAF), and height (DEXA abdominal fat index, AFI) defined as TAF/height² [19].

Statistical tools and analysis

Statistical packages that were used were: *Epi-Info*, version 6.04 (CDC, Atlanta, USA) for data entry, *SPSS*, base version 13 (SPSS Inc, Chicago, Illinois, USA) for correlations and linear regressions, and *Analyse-it®* plus method evaluation (Analyse-it Software Ltd., Leeds, England, UK) for assessing agreement between DEXA body fat composition and values predicted from BMI. Statistical differences were considered significant if the *P*-value was < 0.05 .

Pearson correlation was used to assess the relationship between different body fat measures and BMI metrics for the entire sample and for different subgroups. We

used various combinations for categorizing whole body fat composition, regional distribution and BMI metrics. Since body fat is influenced by many factors, we used multiple regressions to predict whole body fat depending on variables such as BMI, abdominal fat, sex, age and race. ANOVA testing was used to assess the significance of the multiple regression models.

Other standard statistical techniques used were scatter plotting for assessment of linearity, histograms and P-P plot for checking normality of the error term, and transformation/inversion of BMI for correction of heteroscedasticity in the residuals. In multiple regressions, multicollinearity was assessed by tolerance, variance inflation factor, Eigen values and condition indices. Multicollinearity was controlled by rerunning regression with transformed BMI and *z*-scores, by different categorization of whole body and abdominal fat measures and by stepwise model selection. Bias plots such as the difference plot and the Bland–Altman plot were used for assessing agreement between measuring methods.

Results

During the period of study, 748 obese children attended day care in the unit (Table 1); 59.6% were non-Caucasians. Characteristics of these children, including their regional origins and their anthropometric data, are shown in Table 1. Abdominal fat constituted 42.6% of the total body fat.

Examination of BMI against different body fat measurements such as PBF showed that these variables are suitable for linear regression models. Linearity was more evident when other derivatives of BMI such as logBMI, inverse BMI and BMI *z*-score, or adjusted derivatives of body fat such as FMI were used (Figure 1). Pearson correlation

Table 1 Characteristics of the children involved in the study

Variable	No. (%) (n = 748)
Sex	
Boys	324 (43.3)
Girls	424 (56.7)
Geographic origin of mother	
Metropolitan France	310 (41.4)
North Africa	124 (16.6)
Overseas France (mostly the Antilles)	65 (8.7)
Sub-Saharan Africa	51 (6.8)
Other	198 (26.5)
	Mean (SD)
Age (years)	11.66 (2.8)
Anthropometric measures	
BMI (kg/m ²)	30.11 (5.6)
BMI z-score	4.24 (1.0)
Body and regional composition measures	
DEXA body fat (%)	44.21 (8.0)
DEXA abdominal fat (%)	41.78 (5.6)
DEXA total body fat (kg)	32.67 (13.9)
DEXA total abdominal fat (kg)	13.92 (6.56)
DEXA fatty mass index (kg/m ²)	13.61 (4.4)
DEXA abdominal fat index (kg/m ²)	5.78 (2.2)

SD = standard deviation; BMI = body mass index;
DEXA = dual energy X-ray absorptiometry

between BMI and PBF was fair ($r = 0.54$) [20]. Correlations were stronger between BMI and measures such as FMI ($r = 0.89$), PAF ($r = 0.86$) and TAF ($r = 0.90$). Pearson correlation between FMI and AFI was also strong ($r = 0.96$). BMI explained only one-third of the variations in PBF ($R^2 = 0.29$), while it explained more than three-quarters of the variation in FMI ($R^2 = 0.79$).

The correlation between BMI and FMI differed slightly between different groups: boys (0.92) and girls (0.86); age categories (0.89–0.90); geographic origin of the mother, France metropolitan (0.87), North Africa (0.89), Sub-Saharan Africa (0.92),

and France overseas (0.92). In the initial evaluation, the correlation did not differ significantly between those with high AFI (0.88) and low AFI (0.89). Further multi-level division into subgroups showed that the correlation between BMI and FMI was strong ($r > 0.8$) in most of these subgroups. In only 3 of them, the correlation was moderately strong (r ranging from 0.6 to 0.8) (Table 2). Categorizing AFI into pentiles led to a U-shaped correlation between BMI and FMI according to percentile of AFI (Figure 2).

The best model fit, found by stepwise multiple regression, is presented in the following equation: Predicted FMI = $1/[(0.159 - 0.013 \times \text{percentile of TAF}) - (0.01 \times \text{BMI } z\text{-score})]$; where percentile of TAF is an ordinal measure ranging from 1 to 5, while BMI z -score is a continuous variable.

In this model, after adding z -score and abdominal fat to the model, none of the remaining predictors was significant. ANOVA testing showed that the model was statistically significant ($P < 0.01$). The model as revealed by its r value of 0.87 was very strong. It explained 75% of changes in FMI (adjusted R^2). The model's ability to explain body fat compares favourably with that of other models that included other ways for expressing BMI, other body fat composition variables, or adjusted abdominal fat measures such as AFI or PAF. It had low collinearity as indicated by high tolerance of 0.92, low variance inflation factor of 1.084, Eigen value far from zero, and a maximum condition index of < 10.52. Using other predictors such as BMI or logBMI increased collinearity with sex, age, and/or race, as indicated by collinearity diagnostics, without significant gain in correlation strength.

Comparison of the predicted FMI from the proposed equation with DEXA measured FMI showed high agreement as re-

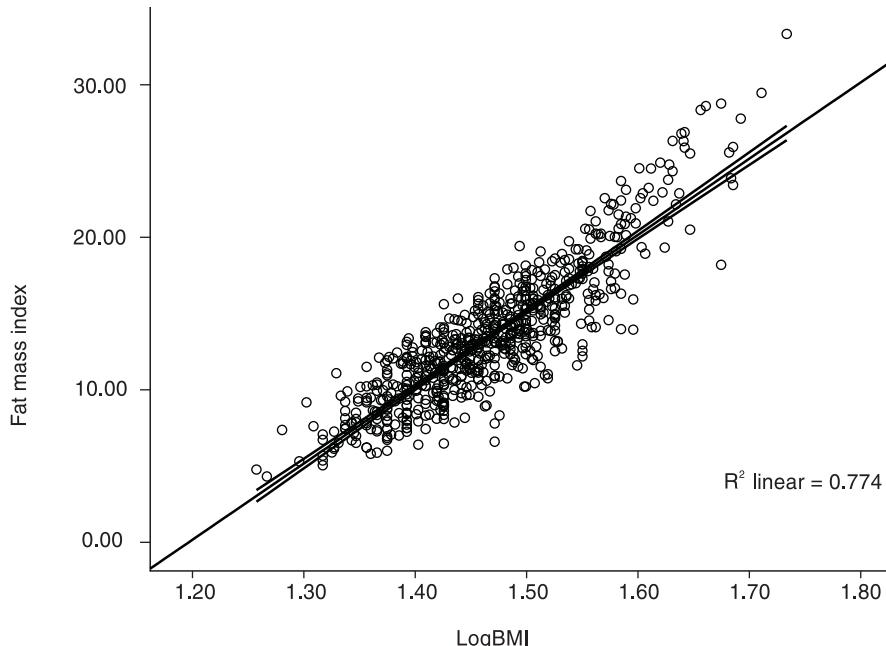


Figure 1 Linear relationship between fat mass index and logBMI ($n = 683$)

vealed by the 2 bias plots, the difference plot and the Bland–Altman plot (Figures 3a and 3b). The 2 methods agreed in 99.8% of measures.

Discussion

BMI is a more reliable measure of fatness than measures such as triceps skin-fold thickness [6]. Still, it is not a precise estimate of the underlying proportion of fat and lean tissue as subjects with the same BMI value do not necessarily have similar levels of obesity [6,21]. In the current study, BMI explained only one-third of PBF, which is within the wide range of 14%–81% found in previous studies [9].

Many previous studies have assessed the ability of BMI to diagnose obesity within a group of the normal population by calculat-

ing sensitivity, specificity, predictive values, receiver operated characteristic curves and area under the curve in comparison to standard techniques [22]. Few studies have assessed BMI in obese children rather than in the normal population [14,16] and the role of abdominal fat has rarely been studied [14,23]. In our study, we had no data on maturational stage, but previous studies have shown that this was not an important factor in either sex [3,24].

The strength of the correlation between BMI and body fat measures previously found ranged from moderate to very strong. Few studies have used BMI z -scores or logBMI [3,22,24]. Using BMI z -score or logBMI and TBF gave stronger correlations than using BMI and PBF [3,9,10,14,22]. This may be related to the curvilinear relationship between BMI and both PBF and

Table 2 Pearson correlation between body mass index and high and low fat mass index in obese children by age group ($n = 501$)

	Boys						Girls												
	Metropolitan France		North Africa		Sub-Saharan Africa		Overseas France		Metropolitan France		North Africa		Sub-Saharan Africa		Overseas France				
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	
<i>Age 1-10 years</i>																			
Number	28	31	23	1	6	2	10	3	48	35	17	9	10	5	14	6			
Correlation	0.88**	0.91**	0.95**	–	0.94**	–	0.95**	0.87	0.87**	0.85**	0.83**	0.94**	0.88**	0.96*	0.65*	0.96**			
<i>Age ≥ 11 years</i>																			
Number	29	33	14	15	1	0	2	8	29	51	11	20	13	8	13	6			
Correlation	0.66**	0.81**	0.88**	0.64*	–	–	–	0.82*	0.91**	0.92**	0.94**	0.95**	0.94**	0.95**	0.95**	0.95**	0.95**		

*Correlation significant at $P < 0.05$; ** Correlation significant at $P < 0.01$.

– No measurement possible.

FMI [25,26]. As in the current study, the use of height-adjusted body fatness indices such as FMI had advantages over unadjusted measures such as TBF or weight-adjusted measures such as PBF in children [25]. FMI is discrete, easy to measure and is expressed in the common unit of BMI [25].

Previous studies have shown that correlations are not equal in the subgroups of sex, age and race. Stronger correlations have been found in girls [9,22], preadolescents and early adolescents [16,27]. For the same BMI values, Hispanic and Asian children have higher PBF, while African-American children have lower PBF values than white children with the same BMI value. Furthermore, ethnic differences were not equal in both sexes [13,28,29]. Studies have shown also that ethnic and gender differences are age-related. In boys, the age-related increase in BMI is accompanied by relatively small changes in FMI, whereas in girls, the age-related increase occurs with a doubling in FMI [25]. In our study, when we stratified sex, age and race subgroups according to abdominal fat content, the strength of correlations in all the subgroups was comparable.

From the current study, the model that best predicted whole body fat with least collinearity was the model incorporating both BMI *z*-score and abdominal fat. Previous regression models in similar studies have reported that variables such as sex, age and race were significant contributors in the equation [14,24]. It is understandable that when we use BMI *z*-score, we would not normally need to adjust for age and sex since the BMI *z*-scores are already age- and sex-adjusted. BMI *z*-score and LogBMI are superior to BMI alone. This is why it is preferable to use BMI *z*-score rather than BMI percentile when we need to explain PBF [3] or monitor weight management interventions [30]. When BMI is used, a decrease

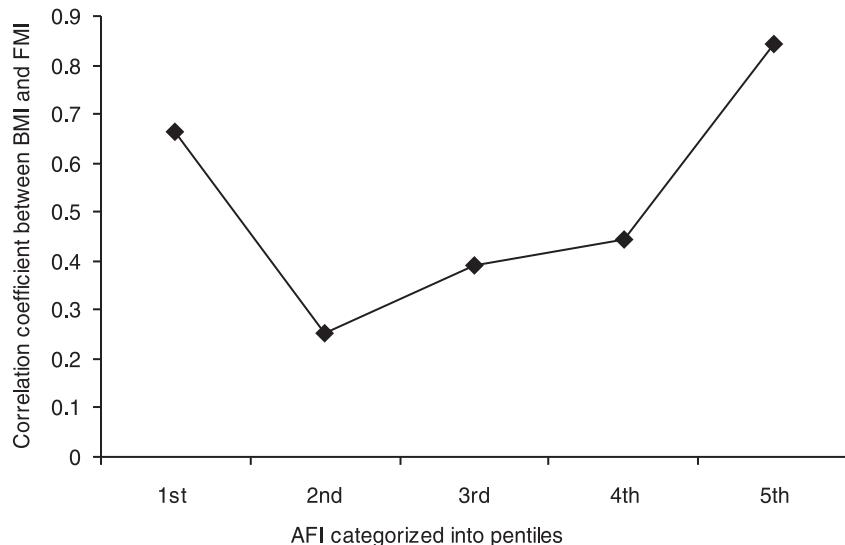


Figure 2 U-shaped correlation between body mass index (BMI) and fat mass index (FMI) according to category of abdominal fat as measured by abdominal fatty index (AFI) ($n = 683$)

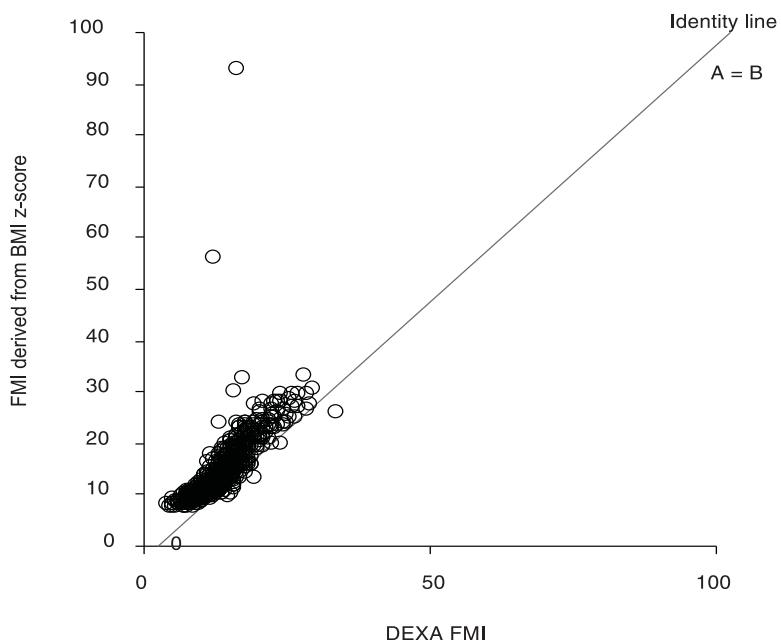


Figure 3a Difference between predicted fat mass index (FMI) and FMI measured by DEXA in obese children ($n = 683$). Predicted FMI = $1/[0.159 - 0.013 \times \text{percentile of total abdominal fat} - (0.01 \times \text{BMI z-score})]$

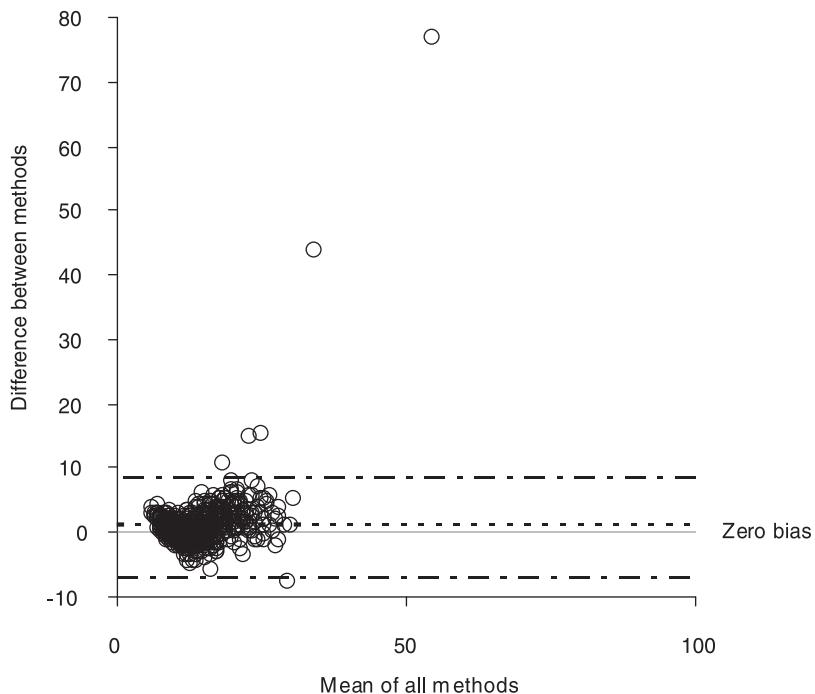


Figure 3b Bland-Altman plot comparing the predicted fat mass index (FMI) and the FMI measured by DEXA in obese children ($n = 683$). The 2 measures agreed in 99.8% of cases. Predicted FMI = $1/[(0.159 - 0.013 \times \text{percentile of total abdominal fat}) - (0.01 \times \text{BMI z-score})]$.

in BMI for a young boy does not have the same meaning as the same decrease in BMI for an older girl.

The absence of ethnic differences found in our study has been previously noted in some other studies [3,27]. Ethnic differences have been attributed to abnormal trunk/leg proportions that could distort the results of BMI and body fat [31]. These ethnic differences may also be attributed to differences in body regional distribution of fat. Previous studies have shown that African-Americans have less intra-abdominal adipose tissue than their Caucasian counterparts [32]. These differences are believed to be acquired since racial differences in regional body composition disappear when

socioeconomic and dietary feeding practices are controlled for [33].

The model in the current study indicates the importance of abdominal fat in whole body fat and its relation with BMI. Some of the previous studies in adults and in children have also noted the importance of abdominal fat in whole body fat [14,34]. The current study postulates that the imprecision seen in BMI as a measure of body fat composition in sex, age and ethnic subgroups may be due to differences in abdominal fat content. These differences in the correlation of BMI to body fat disappear when controlled for by abdominal fat. In addition, the effect of abdominal fat on whole body fat is not necessarily linear, since we only picked

up these differences when abdominal fat values were stratified into 4 or 5 categories. This finding is in line with previous findings that there are particular points at which the abdominal region becomes or ceases to be the main location for storage of fat in body [35]. The contribution of accumulation of fat in the abdomen differs from its accumulation in the whole body as it is less related to height or surface area of the body. In our study no data were available on the waist circumference of the children. Using waist circumference rather than only DEXA-measured abdominal fat would have been useful, as this would have facilitated translation of our findings to daily practice by the construction of a nomogram for prediction of FMI from both BMI z-score and waist circumference.

Correlations measure the degree of association but they do not provide informa-

tion on the accuracy of the measures being correlated. When evaluating the merits of a measure, it is advisable to consider more than the correlation coefficient [3,17]. So we wanted to test whether estimation of FMI from BMI using the equation given earlier could serve as a proxy for DEXA-obtained-FMI in all sex, age and race subgroups. The results of the 2 bias plots showed that the 2 measures are nearly identical and can be used interchangeably.

BMI is a useful measure for total body fat across different ethnic groups, including North Africans and Sub-Saharan Africans, but its use in all ethnic groups is dependant on the amount of deposited abdominal fat. In follow-up of individual children, both BMI and abdominal fat should be looked at as a proxy method to determine whole body fat.

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