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Original Research Article

How Useful Is BMI in Predicting Adiposity Indicators in a Sample of Maya Children and Women with High Levels of Stunting?

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Objectives: Body mass index (BMI) is used frequently to estimate adiposity levels in children and adults. However, the applicability of BMI to populations with high levels of stunting has been questioned. Stunted people can have disproportionately short legs, which may increase BMI without increasing body fat because of the relatively larger trunk compared with the legs.

Methods: A sample of 57 urban Maya schoolchildren, aged 7–9 years (31 boys), and 53 adult women underwent anthropometric assessments and bioelectrical impedance analysis. Multiple linear regression was performed to determine whether the ability of BMI to predict adiposity indicators is altered by stunting and sitting height ratio (SHR). The adiposity indicators were waist circumference, sum of skinfolds, upper arm muscle area, upper arm fat area, and arm fat index.

Results: BMI was the strongest predictor of all adiposity indicators and in most cases, explained more of the variance in adiposity of Maya children than Maya women. Abdominal adiposity was better predicted by BMI than peripheral adiposity in Maya women and Maya children. Stunting was significant in predicting adiposity in some models but never substantially changed the variance explained. SHR was never a significant predictor.

Conclusions: The relationship between BMI and adiposity indicators is not changed by stunting status or body proportions in this short population of urban Maya children and women. BMI can be used as an indicator of adiposity for these children but not the women. It is recommended that BMI is used in conjunction with other estimates of body composition. Am. J. Hum. Biol. 23:780–789, 2011.

Linear growth is determined by a combination of genetics (Aulchenko et al., 2009; Bogin, 1999) and the quality of the environment experienced by the individual (Bogin, 1999). Stunting (very low height-for-age), due to chronically poor conditions, is very common in much of the developing world (Garrett and Ruel, 2005; Van de Poel et al., 2008) including urban centers in Latin America (Van de Poel et al., 2007). Stunting is widespread among indigenous groups (Barquera et al., 2007) and the poor (Malina et al., 2008; Van de Poel et al., 2008). As nutrition transition occurs (Popkin, 1996), stunting rates are declining in Latin America (Malina et al., 2009; Rivera et al., 2004). However, it will be several decades before the stunting rates will be considered acceptable, at a prevalence of less than 5% of the population (Rivera et al., 2004). In this article, adult short stature and childhood stunting will both be referred to as stunting for consistency of presentation. Adult short stature is caused by the same factors as childhood stunting and is in fact the end result of childhood stunting (Bogin, 1999).

Childhood stunting often leads to very short stature in adulthood (Stein et al., 2010). Adults and adolescents with short stature have been shown to have increased mortality rates (Song and Sung, 2008), cardiovascular risk factors, (Florencio et al., 2007; Kruger et al., 2004) and lower economic productivity (Case and Paxson, 2008). Also short adults are at an increased risk of obesity (Hoffman et al., 2000b, c; Leonard et al., 2009; Lopez-Alvarenga et al., 2003; Martins et al., 2004). The dual burden of simultaneous short stature and obesity is increasingly common in developing countries individuals (Doak et al., 2005, 2000). With limited resources available, these countries need an efficient and cost effective method of assessing over and undernutrition to be able to monitor and diagnose dual burdened populations.

Body mass index (BMI = weight in kg/stature in meters^2) is often used to assess nutritional status and screen for obesity. Although BMI is not intended to distinguish individuals who have excess adipose tissue (Ellis, 2001), in practice it has become the most widely used indicator of overweight, both in clinical settings and in research (Burkhauser and Cawley, 2008; Hall and Cole, 2006; Popkin and Doak, 1998). BMI is very easy to measure, with minimal training, requiring only stature and weight measurements (Burkhauser and Cawley, 2008; Ellis, 2001) and it has been shown to correlate fairly well with total body adiposity (Cameron et al., 2009; Ellis, 2001). It is useful for longitudinal measurements of adults as adult stature is constant and therefore changes in BMI may be considered to be mostly due to body fat (Ellis, 2001). BMI is recommended mainly for large, popu-

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lation-based studies (Burkhauser and Cawley, 2008; Ellis et al., 1999).

The main limitation of BMI is the inability of the tool to differentiate between fat and fat-free mass. Individuals, both children and adults, with normal or overweight BMIs may have a percent body fat (%BF) that is over the cut off for overfat (Ellis, 2001; Frankenfield et al., 2001). People with high fat-free mass, such as some athletes and those engaged in physically demanding occupations, may have a high BMI but a normal or low %BF (Burkhauser and Cawley, 2008). Therefore, when used as a screening tool for obesity, BMI is not precise because it has a low sensitivity (ability to classify overfat individuals) (Ellis, 2001). The problems with using BMI as a screening tool may be especially true in non-Western populations that may have ratios of fat mass to fat free mass (Norgan, 1994a) or fat patterning (Fuke et al., 2007; Gabrielsson et al., 2003; Lau et al., 2005; Norgan, 1994a) different from that of the majority of people living in industrialized nations of Europe and North America.

Nutritionally stunted populations pose a theoretical problem to the use of BMI. First of all, as stature is squared in the denominator of the BMI equation, a reduction in stature will lead to an exaggerated increase in BMI, the effect of which will be greater in children than adults (Cameron et al., 2005). Secondly, body proportions may be altered in stunted individuals due to the body's growth patterns in childhood. The legs are the fastest growing segment of the body before puberty (Leitch, 1951). If the chronically poor conditions that caused the stunting occurs during childhood, the legs may be disproportionately short (Gunnell et al., 1998). Short legs and a long torso will result in a higher body weight due to the size differences between the limbs and torso (Bogin and Beydoun, 2007; Norgan, 1994b). The higher weight will result in a higher BMI, without any change to body composition. This may render BMI inappropriate for use in stunted individuals, especially in those with disproportionately long or short legs.

Norgan (1994a) found that skinfold thickness was greater than expected from the BMI of Australian Aborigines. Australian Aborigines have relatively long legs for their height, which results in a low sitting height ratio (SHR = [sitting height/stature] $\times$ 100) and, it seems, a low BMI. In a sample of 349 adult Aboriginal men and women Norgan found that, "…4% of the individual men and 14% of the individual women had [BMI] values less than 16 kg/m^2, a value regarded as indicating severe chronic energy deficiency" (p.229). Skinfold measurement, however, indicated no such deficiency. In a related analysis of more than 18,000 nonwestern adults, Norgan (1994b) found that linear regression of BMI on SHR resulted in regression coefficients ($b \pm$ standard error) of 0.78 ± 0.16 ($t = 4.8$) in men and 1.19 ± 0.22 ($t = 5.3$) in women. These regression coefficients compare with a predicted change of 0.9 kg/m^2 per 0.01 difference in SHR using a modeling approach. The predictive model proves inaccurate for both men, in which the model overestimates the change, and women, in which the model underestimates the change. Norgan concludes that the wide variation in these relationships between the sexes and between populations precludes a simple adjustment for SHR on BMI. Norgan also points out that an accurate interpretation of BMI requires additional anthropometric measurements to just height and weight. Norgan's findings have been confirmed other studies. In a sample of 120 Chinese and Dutch adults matched for age, sex, and BMI, Deurenberg et al. (1999) found that BMI varied according to SHR. Relatively shorter legs were associated with greater BMI. Two analyses of the United States Third National Health and Nutrition Survey of 1988–1994 (NHANES III) find that adults with relatively shorter legs as estimated by the SHR have greater fatness (Asao et al., 2006; Bogin and Beydoun, 2007). Another study indicates that the cause of the relationship may be greater gluteal-femoral fatness artificially increasing sitting height and as a consequence artificially decreasing the estimate of leg length relative to total stature (Bogin and Varela-Silva, 2008). Lara-Esqueda et al. (2004) showed that BMI did not work as well in detecting cardiovascular disease risk factors in stunted versus nonstunted Mexican adults.

All of these studies indicate that therefore, a high BMI in very short populations may not be useful in assessing nutritional status. However, it is not clear if these problems with BMI outweigh its usefulness as an indicator of risk for later negative health outcomes in all populations, including stunted populations.

The Maya are indigenous to Central America, including the Yucatan Peninsula. They are a poor, marginalized group of society, which also places them at risk for negative health outcomes. The Mayans tend to be very short, with high levels of stunting (Bogin et al., 1992; Crooks, 1994; Jenkins, 1981). Using data collected in 2007 from the same neighborhoods of Merida, Mexico sampled in this study, Varela-Silva et al. (2009) found that 22% of 4–6-year-old Mayan children were stunted. Stunting was even more common in their mothers, with 69% being under 150 cm tall (Varela-Silva et al., 2009). Also, the Mexican Maya are adopting behaviors (Leatherman and Goodman, 2005; Leatherman et al., 2000) which have been linked to increased obesity and other chronic disease (Leatherman et al., 2010). These characteristics make the Maya a suitable population in which to examine the usefulness of BMI as a predictor of obesity.

Accordingly, this study aims to determine whether BMI is an appropriate estimate of adiposity in stunted and nonstunted urban Maya women and their 7- to 9-year-old children. This study also aims to determine if the association between BMI and adiposity indicators is influenced by body proportions. The age range of 7–9 years in children is useful to examine in relation to the effects of stature on adiposity measures because it is a period of stable growth before puberty (Cameron, 2002). Though it must be noted, it is too old to reverse stunting (Walker et al., 2007) and its effects (Hoffman et al., 2000a; Martins et al., 2004).

MATERIALS AND METHODS

Sample

A cross-sectional survey was undertaken of 58 urban Maya mothers and their children (31 boys), aged 7 to 9 years old, living in Merida, Yucatan, Mexico between March and July of 2010.

Recruitment

Schools located in *colonias* (neighborhoods) in the southern part of Merida, Mexico, that had a high proportion of Maya students were approached. School directors that agreed to participate provided the school lists with the children's full names. From these lists, Maya children were identified as those with two Maya surnames, one from both the father and the mother. The mothers were then invited to information sessions at their children's schools where the study was explained and information sheets were provided. The mothers and one of their children aged 7 to 9 years were recruited. The survey involved administering a semistructured interview to the mother, anthropometric and body composition measurements of the mother and child, and monitoring the physical activity levels of the child.

Pubertal status of the girls was also assessed by maternal interview. Pubertal status of the boys was not assessed due to the later development of boys. Only two of the 26 girls were determined to be pubertal, all analyses were performed with and without these two individuals. The results did not differ between the two separate analyses and therefore the findings from the full sample are shown to maximize the sample size available for analysis.

Written informed consent was obtained from the mothers and verbal assent from the children. Ethical clearance was obtained from the Loughborough University Ethics Committee in the U.K. and the Bioethics Committee of Human Studies of Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional (Cinvestav) in Mexico.

Measurements

Mothers and children underwent anthropometric measurement (Lohman et al., 1988), which included stature, sitting height, weight, waist circumference (WC), mid-arm circumference, and skinfolds (triceps for both mother and children and subscapular, for children only). The sum of two skinfolds (triceps and subscapular) (2SF) was calculated for children (Frisancho, 2008). Body mass index (BMI) was calculated by dividing weight in kilograms by stature in meters squared. Sitting height ratio (SHR) was calculated by dividing sitting height by stature and multiplying by 100. Arm fat index (AFI) was calculated by dividing arm fat area (UFA) by mid-upper arm area (UMA) for an estimation of the fat percentage of the arm (Frisancho, 2008).

Body composition was measured for women and children using bioelectric impedance analysis (BIA) with a BioScan 916, Maltron International. Percent body fat (%BF) was calculated using the impedance and reactance values with equations for North American Indian children [Eq. (1)] (Lohman et al., 1999) and women [Eq. (2)] (Stolarczyk et al., 1994) from the southwest of the United States. North American Indian equations were used because no equations specific to the Maya have been published. Maternal fat free mass as calculated by Eq. (2) was converted to %BF. The equation for women [Eq. (2)] had a reported r^2 of 0.803 and a standard error of estimate (SEE) of 2.38 kg for fat mass (Stolarczyk et al., 1994). The equation for children [Eq. (1)] has a SEE of 3.4% body fat and no r^2 was reported (Lohman et al., 1999).

Equation 1: Child's percentage body fat $= -0.49$ age $+ 0.51$ sex $+ 0.44$ weight $+ 1.55$ triceps skinfold $+ 0.15$ subscapular skinfold $+ 0.54$ (stature^2/resistance) $+ 0.13$ reactance $- 0.04$ triceps skinfold $\times$ stature^2/resistance $- 10.91$

Equation 2: Women's fat free mass (kg) $= 0.001254$ (stature^2) $- 0.04904$ resistance $+ 0.155$ weight $+ 0.1417$ reactance $- 0.0833$ age $+ 20.05$

Definitions: Sex coded 1 for girls, 0 for boys. Weight is in kg. Skinfold thicknesses are in mm.
Resistance and reactance are in ohms. Stature is in m for Equation 1 and centimeters for Equation 2.

Frisancho's Comprehensive sex- and age-specific reference charts were used to calculate *z*-scores and classify children as stunted (2008). This reference was chosen as it was created using NHANES III data from the USA, which includes Mexican–Americans. Women were classified as stunted if their stature was below 150 cm, the nearest whole centimeter to the 5th percentile for adult women from Frisancho's Comprehensive reference (Frisancho, 2008). This cut off has been used previously in Mexican women (Lara-Esqueda et al., 2004; Lopez-Alvarenga et al., 2003; Varela-Silva et al., 2009). Children were classified as being stunted if their height-for-age was below the 5th percentile. For children, age- and sex-specific *z*-scores were calculated for WC, BMI, AFI, and 2SF. No reference values were available for children's %BF as the references begin at age 12.

Statistical analysis

Normality of all variables was checked. Descriptive statistics were performed and Pearson's correlations, independent *t*-tests, and Pearson's chi square were used for inferential analysis. A simple linear regression was also performed with BMI as the dependent variable and SHR as the predictor variable for women and children separately in order to be able to compare these findings with previous studies.

Multiple linear regressions were performed using the enter method with adiposity indicators as the dependent variables, which were determined based on theory related to the hypothesized effects of the predictor variables in their association with the outcome measure. The independent variables were BMI, stunting, and SHR. To determine whether BMI interacted with stunting or SHR to influence the dependent variable, an interaction between each was included. For model building purposes and to allow for potential moderating effects of other variables, if an interaction had a P value below 0.10 in the simple model, it was included in the final model. No more than four predictor variables were used in a single regression model, giving these models the power to detect large, but not small to medium effect sizes due to the size of the sample (Cohen, 1992).

The dependent variables for the children's models were %BF and the *z*-scores of WC, 2SF, UMA, UFA, and AFI. All continuous variables in the children's regressions were *z*-scores, except for %BF (Frisancho, 2008). Therefore, in the children's %BF model, age and sex were also entered into the model because %BF was not already standardized for age and sex. The dependent variables for the women's models were WC, %BF, UMA, UFA, and AFI.

Stature is also used to calculate both BMI and SHR, which could potentially lead to colinearity. However, the purpose of squaring stature in the denominator of the

TABLE 1. Children's descriptive statistics, mean (SD)[a,b]

	Boys	Girls	Stunted	Nonstunted	All
N (%)	31 (54.4)	26 (45.6)	18 (31.6)	39 (68.4)	57 (100)
Age	8.23 (0.84)	8.59 (0.72)	8.33 (0.85)	8.47 (0.78)	8.43 (0.8)
Stature	121.84 (5.95)	122.54 (7.94)	115.57 (5.72)††	125.2 (4.99)††	122.13 (6.82)
Stature *z*-score	−1.12 (0.86)	−1.20 (0.89)	−2.14 (0.47)††	−0.7 (0.58)††	−1.15 (0.87)
Weight	25.76 (4.83)	28.38 (7.92)	22.51 (2.47)††	29.00 (5.94)††	26.87 (6.47)
Weight *z*-score	−0.64 (0.81)	−0.21 (0.93)	−1.09 (0.7)††	−0.14 (0.81)††	0.44 (0.89)
BMI[c]	17.24 (2.31)	18.62 (3.70)	16.74 (3.22)	18.39 (2.91)	17.83 (3.07)
BMI *z*-score	0.48 (0.88)	0.67 (1.03)	0.14 (0.94)†	0.76 (0.9)†	0.56 (0.95)
Sitting height	65.48 (2.69)	65.75 (7.92)	62.86 (3.23)††	66.87 (2.73)††	65.6 (3.43)
Sitting height *z*-score	−0.97 (0.80)	−0.51 (0.97)	−1.42 (0.74)††	−0.45 (0.81)††	0.76 (0.9)
SHR[d]	53.77 (1.28)	53.68 (1.38)	54.40 (1.41)††	53.42 (1.15)††	53.73 (1.31)
SHR *z*-score	1.02 (0.74)	1.26 (0.89)	1.57 (0.87)††	0.9 (0.72)††	1.13 (0.82)
WC (cm)[e]	58.51 (5.86)	61.4 (9.6)	55.98 (6.83)†	61.60 (7.73)†	59.77 (7.8)
WC *z*-score	0.14 (0.70)*	0.58 (0.84)*	−0.02 (0.66)†	0.51 (0.8)†	0.34 (0.79)
Triceps skinfolds (mm)	12.58 (6.44)	15.30 (6.14)	12.03 (5.98)	14.64 (6.49)	13.75 (6.36)
Triceps skinfold *z*-score	0.45 (0.88)	0.75 (0.93)	0.27 (0.86)	0.73 (0.9)	0.58 (0.91)
Subscapular skinfold (mm)	9.14 (5.43)*	12.65 (7.23)*	8.71 (5.15)	11.62 (6.89)	10.62 (6.46)
Subscapular skinfold *z*-score	0.61 (0.79)	0.84 (0.92)	0.35 (0.8)†	0.89 (0.83)†	0.72 (0.85)
Sum of 2 skinfolds (mm)[f]	21.71 (11.58)	27.42 (12.63)	20.74 (10.82)	26.00 (12.72)	24.37 (12.31)
Sum of 2 skinfolds *z*-score	0.33 (0.99)	0.82 (0.84)	0.25 (0.88)	0.7 (0.95)	0.56 (0.95)
Mid-arm circumference (cm)	19.05 (2.34)*	20.94 (4.16)*	18.27 (2.89)†	20.67 (3.38)†	19.88 (3.38)
Mid-arm circumference *z*-score	−0.56 (0.94)	0.74 (1.17)	−0.39 (1.01)	0.23 (1.28)	0.03 (1.23)
TUA (cm^2)[g]	29.3 (7.27)*	36.22 (15.28)*	27.17 (9.59)†	34.89 (12.36)†	32.33 (11.96)
TUA *z*-score	−0.07 (0.92)	0.46 (1.09)	−0.33 (0.84)†	0.4 (1.03)†	0.17 (1.02)
UMA (cm^2)[h]	18.31 (3.59)	21.47 (9.16)	16.76 (4.68)†	21.04 (7.34)†	19.71 (6.79)
UMA *z*-score	−1.18 (1.01)	−0.58 (1.59)	−1.53 (1.00)†	−0.62 (1.37)†	−0.91 (1.33)
AFA (cm^2)[i]	10.98 (6.36)	14.74 (8.11)	10.21 (6.52)	13.84 (7.56)	12.62 (7.35)
AFA *z*-score	0.54 (1.23)	0.68 (1.18)	0.12 (1.07)†	0.82 (1.2)†	0.6 (1.2)
AFI (%)[j]	35.55 (12.51)	39.67 (10.25)	35.66 (11.12)	38.25 (11.91)	37.34 (11.54)
AFI *z*-score	0.91 (1.22)	1.26 (1.37)	0.79 (1.2)	1.2 (1.33)	1.07 (1.29)
%BF[k]	26.54 (0.65)*	30.24 (7.22)*	25.09 (6.72)†	29.68 (6.76)†	28.23 (7.03)

[a]All sex- and age-specific *z*-scores calculated using Frisancho's comprehensive reference (2008).
[b]Stunted defined as height-for-age below the 5th percentile of sex-specific Frisancho's comprehensive reference curves.
[c]BMI, body mass index = (weight in kilograms/stature in metres^2).
[d]SHR, sitting height ratio = (sitting height/stature) × 100.
[e]WC, waist circumference.
[f]The skinfolds summed were triceps and subscapular.
[g]TUA, total upper arm area (Frisancho, 2008).
[h]UMA, upper arm muscle area (Frisancho, 2008).
[i]AFA, arm fat area (Frisancho, 2008).
[j]AFI, arm fat index, percent of the upper arm that is fat (Frisancho, 2008).
[k]%BF, percent body fat calculated from an bioelectric impedance equation specific to American Indian children (Lohman et al., 1999).
*Significant differences between stunted and nonstunted children found using an independent *t*-test, $P < 0.01$.
†Significant differences between stunted and nonstunted children found using an independent *t*-test, $P < 0.05$.
††Significant differences between the sexes found using an independent *t*-test, $P < 0.05$.

BMI calculation is to remove the influence of stature and to obtain an overall measure of body size. Multicolinearity of the variables were checked and none excluded the tolerated values (VIF < 1.0) (Bowerman and O'Connell, 1990). Thus, it was deemed statistically as well as theoretically appropriate to use both BMI and SHR as predictors in the same regression model.

All analyses were done using SPSS v. 17.0. Significance was set a priori at $P < 0.05$.

RESULTS

One child and one woman were excluded due to biologically improbable sitting heights. Also, four mothers were excluded due to missing BIA data. The final sample sizes were 57 children (31 boys) and 53 women.

For the children, no significant difference in the prevalence of stunting between the sexes was found ($P > 0.05$). Overall, the children were quite small. Significant differences between the sexes were found for WC *z*-score, arm circumference, and %BF, with girls being larger and having more body fat than boys. The stunted children were consistently smaller overall than their nonstunted peers (Table 1).

The women were very short, with 75% being stunted, and had high levels of adiposity. However, no significant differences existed between the stunted and nonstunted mothers with respect to the adiposity indicators such as %BF, BMI, WC, AFI, etc... (Table 2).

The children's BMI and SHR were not significantly related ($R^2 = 0.001$) (Fig. 1a). However, the women's BMI and SHR were significantly related ($R^2 = 0.102$) (Fig. 1b).

For children, BMI was the largest contributor to each model, explaining between 31% (UMA) and 84% (WC) of the variance when significant (Tables 3 and 4). BMI significantly and positively predicted all adiposity indicators and was the only significant predictor for %BF, AFI, and 2SF. The variance explained by the models varied little with the inclusion of covariates other than BMI, including stunting and SHR. %BF had the largest change in variance explained with 0.5% from the BMI only model to the final model. Stunting was statistically significant in some models but it never explained more than 2% of the variance in the adiposity outcomes. The interaction between BMI and stunting significantly and negatively predicted WC. The plot of the interaction shows that nonstunted children have a stronger relationship between BMI and

TABLE 2. Mother's descriptive statistics, mean (SD)[a]

	Stunted	Nonstunted	All
N (%)	40 (75.5)	13 (24.5)	53 (100)
Age	33.74 (6.74)	36.61 (4.16)	34.44 (6.3)
Stature (cm)	145.15 (3.73)*	152.66 (2.10)*	147.00 (4.7)
Weight (kg)	61.81 (9.74)**	69.58 (9.28)**	63.72 (10.12)
BMI[b]	29.32 (4.31)	29.85 (3.84)	29.45 (4.17)
Sitting height (cm)	77.97 (2.30)*	81.32 (2.04)*	78.79 (2.65)
SHR[c]	53.73 (1.10)	53.26 (0.87)	53.61 (1.06)
WC (cm)[d]	87.98 (8.43)	88.94 (9.2)	88.22 (8.55)
Triceps skinfold (mm)	28.42 (8.71)	33.04 (7.05)	29.55 (8.51)
Mid-arm circumference	30.28 (3.64)	31.62 (2.44)	30.62 (3.42)
TUA (cm^2)[e]	73.98 (17.57)	80.26 (12.34)	75.52 (16.56)
UMA (cm^2)[f]	36.82 (8.50)	36.19 (4.04)	36.67 (7.62)
AFA (cm^2)[g]	37.16 (13.68)	44.07 (11.32)	38.86 (13.38)
AFI[h]	49.35 (10.39)	54.24 (6.67)	50.55 (9.79)
%BF[i]	42.93 (4.19)	40.49 (4.27)	42.33 (4.30)

[a]Adult female stunting defined as stature below 150 cm.
[b]BMI, body mass index = (weight in kilograms/stature in metres^2).
[c]SHR, sitting height ratio = (sitting height/stature) × 100.
[d]WC, waist circumference.
[e]TUA, total upper arm area (Frisancho, 2008).
[f]UMA, upper arm muscle area (Frisancho, 2008).
[g]AFA, arm fat area (Frisancho, 2008).
[h]AFI, arm fat index, percent of the upper arm that is fat (Frisancho, 2008).
[i]%BF, percent body fat calculated from an bioelectric impedance equation specific to American Indian women (Stolarczyk et al., 1994).
*Significant differences between the stunted and nonstunted mothers found using an independent *t*-test, $P < 0.01$.
**Significant differences between the stunted and nonstunted mothers found using an independent *t*-test, $P < 0.05$.

WC (Fig. 2). SHR was not significantly associated with any adiposity indicator.

For women, BMI significantly predicted every adiposity indicator and was the largest contributor to each model, explaining between 13% and 78% of the variance (Tables 5 and 6). However, all of the women's models explained less of the variance in adiposity than the children's models. Covariates (BMI, stunting, and SHR) explained more of the variance in women than children. %BF had the largest change in variance explained with a 10% increase from the BMI only model to the final model. Being stunted significantly predicted a higher %BF. SHR did not impact any model though it did significantly interact with BMI in the simple %BF models, but was attenuated in the final models with the inclusion of stunting.

DISCUSSION

In children, BMI significantly predicted measures of abdominal (WC) and total body adiposity (%BF, 2SF) but not peripheral adiposity (AFA, AFI) and explained a high proportion of the variance for all significant variables. Stunting status did not modify the power of BMI to predict adiposity indicators. SHR neither significantly moderated nor mediated the effect of BMI on adiposity outcomes. This suggests that BMI is an appropriate tool to estimate total and central adiposity in this sample of 7–9-year-old children, regardless of SHR.

In women, BMI significantly predicted abdominal adiposity (WC) but not peripheral (AFA, AFI) or total body adiposity (%BF). Stunting independently predicted a higher %BF, but did not change the association between BMI and adiposity indicators in any regression model. SHR was neither significant nor altered the association between BMI and any adiposity indicator. BMI appears to be appropriate for use in these adult urban Maya women only to predict abdominal adiposity.

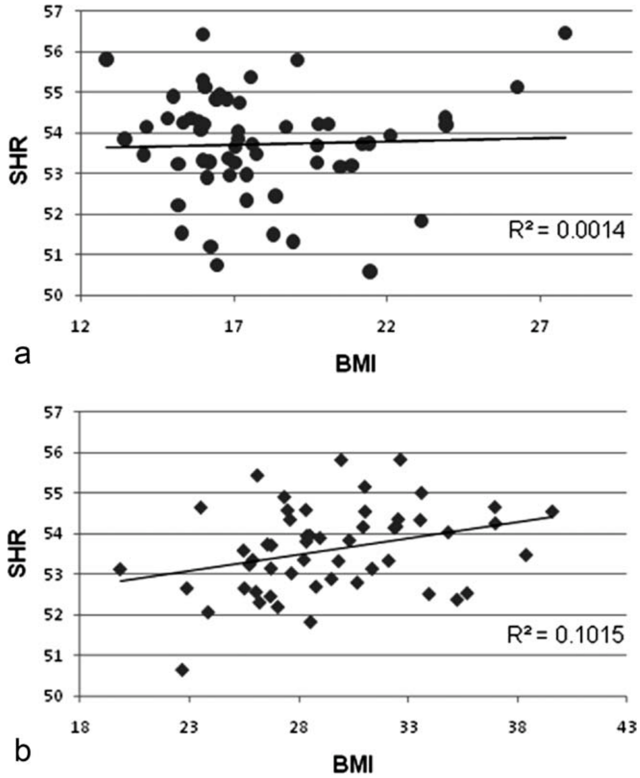

Fig. 1. Simple regression of children's (a) and women's (b) SHR on BMI. Children's raw data was used (not *z*-scores).

Maternal %BF was not well predicted by BMI as it only explained 30% of the variance. This sample of women falls in a range of BMIs (25–29.99) that has been previously shown to be the worst at classifying %BF (Ellis, 2001). Indeed, the %BF of these women was very high (mean = 42%) as measured by BIA. As such, it is not appropriate to use BMI alone to predict %BF in this sample of adult urban Maya women.

The relationship between BMI and %BF in the children is considerably stronger than in the mothers. BMI explained just over 80% of the variance in children's %BF. Similar studies have been done in other samples of children to determine the relationship between BMI and %BF. Ellis et al. (1999) compared BMI to dual X-ray absorptiometry (DXA) in children aged 3 to 18 years in the USA. They found the two estimates of body fat to be significantly correlated, with the relationship stronger in the girls ($r^2 = 0.70$) than boys ($r^2 = 0.34$).

Hoffman et al. (2006) performed a case control study of stunted and nonstunted children in the shantytowns of São Paulo, Brazil (Hoffman et al., 2006). They found that BMI significantly predicted %BF, as measured by DXA but had a much lower r^2 (0.125) than this study (0.807, Table 3, model 1). This large difference may be due, to a combination of measurement error in this study but also to the low levels of adiposity found by Hoffman. This study of Mayans used BIA and predictive equations validated on a group of North American Indians (Lohman et al., 1999; Stolarczyk et al., 1994). BIA and prediction equations have larger measurement error than the gold standard method of DXA (Going et al., 2006), which may have artifi-

TABLE 3. Estimates of child's body composition using multiple linear regression[a]

		Model 1		Model 2		Model 3		Model 4	
		B (SE)	*P*	*B* (SE)	*P*	*B* (SE)	*P*	*B* (SE)	*P*
%BF[b]	Constant	11.991 (4.412)	0.009	12.201 (4.784)	0.014	12.111 (4.708)	0.013	12.745 (4.442)	0.006
	Age	1.393 (0.528)	0.001	1.363 (0.544)	0.015	1.338 (0.554)	0.019	1.272 (0.527)	0.215
	Sex[c]	2.089 (0.839)	0.016	2.300 (0.888)	0.012	2.004 (0.858)	0.023	2.338 (0.863)	0.606
	BMI[d]	6.291 (0.437)	<0.001	6.769 (1.419)	<0.001	6.238 (0.454)	<0.001	5.988 (0.466)	<0.001
	Stunted[e,f]			−1.214 (0.979)	0.221			−1.687 (1.032)	0.108
	BMI × Stunted			−0.494 (0.999)	0.623				
	SHR[g]					0.351 (0.538)	0.517	0.751 (0.548)	0.176
	BMI × SHR					0.185 (0.505)	0.716		
	R^2 adj	0.807		0.806		0.802		0.812	
WC[h]	Constant	−0.090 (0.049)	0.074	−0.237 (0.099)	0.020	−0.105 (0.079)	0.188	−0.257 (0.114)	0.029
	BMI	0.764 (0.045)	<0.001	1.036 (0.137)	<0.001	0.777 (0.046)	<0.001	1.039 (0.139)	<0.001
	Stunted			−0.098 (0.095)	0.309			−0.113 (0.105)	0.288
	BMI × Stunted			−0.211 (0.097)	0.035			−0.215 (0.099)	0.034
	SHR					0.010 (0.055)	0.860	0.020 (0.056)	0.722
	BMI × SHR					−0.059 (0.050)	0.241		
	R^2 adj	0.841		0.846		0.836		0.844	
Sum of 2 Skinfolds[i]	Constant	0.083 (0.080)	0.306	−0.056 (0.167)	0.738	−0.038 (0.128)	0.765	−0.024 (0.127)	0.852
	BMI	0.839 (0.093)	<0.001	1.029 (0.232)	<0.001	0.842 (0.075)	<0.001	0.836 (0.079)	<0.001
	Stunted			0.049 (0.160)	0.761			0.008 (0.170)	0.962
	BMI × Stunted			−0.134 (0.164)	0.417				
	SHR					0.107 (0.089)	0.233	0.093 (0.093)	0.321
	BMI × SHR					−0.039 (0.081)	0.634		
	R^2 adj	0.702		0.696		0.699		0.698	

[a]All variables expect stunting and percent body fat are age- and sex-specific *z*-scores calculated from Frisancho's Comprehensive reference (2008).
[b]%BF, percent body fat calculated from an bioelectric impedance equation specific to American Indian children (Lohman et al. 1999).
[c]Boys were set as the reference.
[d]BMI, body mass index.
[e]Stunting defined as height-for-age below the 5th percentile of Frisancho's Comprehensive reference (2008).
[f]Nonstunted was set as the reference.
[g]SHR, sitting height ratio.
[h]WC, waist circumference.
[i]The summed skinfolds were triceps and subscapular.

TABLE 4. Estimates of child's arm composition in multiple linear regression[a]

		Model 1		Model 2		Model 3		Model 4	
		B (SE)	*P*	*B* (SE)	*P*	*B* (SE)	*P*	*B* (SE)	*P*
UMA[b]	Constant	−1.356 (0.170)	<0.001	−1.328 (0.351)	<0.001	−1.246 (0.276)	<0.001	−1.182 (0.268)	<0.001
	BMI[c]	0.794 (0.155)	<0.001	0.984 (0.488)	0.049	0.794 (0.162)	<0.001	0.723 (0.166)	<0.001
	Stunted[d,e]			−0.499 (0.337)	0.144			−0.468 (0.361)	0.200
	BMI × Stunted			−0.195 (0.346)	0.575				
	SHR[f]					−0.098 (0.191)	0.611	0.013 (0.198)	0.948
	BMI × SHR					0.025 (0.175)	0.899		
	R^2 adj	0.311		0.314		0.288		0.310	
AFA[g]	Constant	0.002 (0.102)	0.982	−0.071 (0.213)	0.740	−0.177 (0.162)	0.279	−0.135 (0.159)	0.401
	BMI	1.060 (0.093)	<0.001	1.207 (0.296)	<0.001	1.058 (0.095)	<0.001	1.021 (0.098)	<0.001
	Stunted			−0.073 (0.205)	0.721			−0.192 (0.214)	0.373
	BMI × Stunted			−0.116 (0.210)	0.582				
	SHR					0.160 (0.112)	0.158	0.194 (0.117)	0.103
	BMI × SHR					−0.029 (0.103)	0.777		
	R^2 adj	0.699		0.690		0.699		0.703	
AFI[h]	Constant	0.613 (0.163)	<0.001	0.605 (0.342)	0.083	0.363 (0.261)	0.169	0.383 (0.257)	0.413
	BMI	0.804 (0.148)	<0.001	0.765 (0.476)	0.114	0.797 (0.153)	<0.001	0.781 (0.159)	<0.001
	Stunted			0.111 (0.329)	0.738			−0.070 (0.346)	0.838
	BMI × Stunted			0.041 (0.337)	0.904				
	SHR					0.225 (0.180)	0.217	0.235 (0.189)	0.221
	BMI × SHR					−0.020 (0.165)	0.903		
	R^2 adj	0.336		0.313		0.332		0.332	

[a]All variables expect stunting and percent body fat are age- and sex-specific *z*-scores calculated from Frisancho's comprehensive reference (2008).
[b]UMA, upper arm muscle area (Frisancho, 2008).
[c]BMI, body mass index.
[d]Stunting defined as height-for-age below the 5th percentile of Frisancho's comprehensive reference (2008).
[e]Nonstunted was set as the reference.
[f]SHR, sitting height ratio.
[g]AFA, arm fat area (Frisancho, 2008).
[h]AFI, arm fat index, percent of the upper arm that is fat (Frisancho, 2008).

cially increased the %BF estimations of these Maya. This increase in estimated %BF may have artificially inflated the relationship between %BF and BMI found in this study. This is particularly the case since age, sex, weight, and stature are included in both the estimation equations for %BF and as predictor variables in this analysis.

It is also possible that a difference in living conditions between the shantytowns of Sao Paulo and the south of Merida caused a difference in the %BF of these children. Hoffman et al. reported low levels of total body adiposity, with the mean %BF 0.559 z-scores below the mean for the Maya of this study. In this study, all families had permanent housing and access to running water inside their property. All the children went to school (4 h a day) and almost all drank purified water (unpublished results). Hoffman's sample was drawn from shantytowns however the living conditions were not described. It is possible that the living conditions of the shantytowns may be worse than those found in the south of Merida. The relatively high standard of living conditions of participants in this study may have led to a higher %BF.

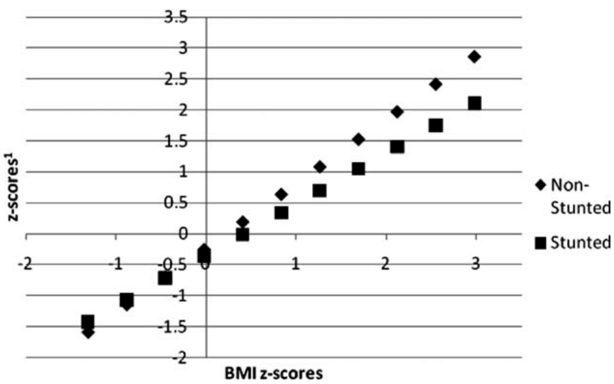

Fig. 2. Children's predicted WC z-scores from the interaction of BMI and stunting. [1]WC z-scores predicted by the final model for WC, as shown in Table 3, model 4.

It is well established that BMI better predicts %BF within the range of healthy BMIs than at low BMIs (Ellis, 2001). Therefore, when measuring children in transitioning societies who are poor, but still have basic sanitation and can afford to send a child to school, BMI may be an appropriate estimate of adiposity. This is primarily true when more accurate body composition methods are not available such as in medical clinics with limited time, equipment, and funding.

In this study, waist circumference was the best adiposity indicator predicted by BMI with nearly 80% of the variance in WC explained by BMI alone in both mothers' and children's models. BMI has been previously shown to correlate well with abdominal adiposity in the rapidly urbanizing and transitioning society in urban South African children of this age range (Cameron et al., 2009) and adults (Harris et al., 2000). In part this may be due to the influence of frame size on both BMI and WC. In adults, BMI and WC have been shown be broadly similar in relation to adult CVD risk (Huxley et al., 2010; Satoh et al., 2010). Most studies involving individuals of non–European descent have found that WC has a greater impact on CVD risk than BMI, though the difference in magnitude is small enough that the clinical relevancy is questionable (Huxley et al., 2010).

Stunting did not alter the relationship between BMI and other adiposity indicators. Also, stunting was rarely significant in these models and had a low beta value in every model. This result suggests that BMI can be used in stunted populations in the same way as it is used in non-stunted populations. BMI appears to be a useful estimate of adiposity, especially when used in conjunction with other measures of body composition.

The hypothesis that differences in SHR change the relationship between BMI and adiposity indicators is not supported by this study of urban Mexican Mayans. Although SHR does impact BMI itself, it does not appear to significantly influence BMI as an estimate of adiposity indicators in this sample. This is surprising as the theoretical basis of this assumption is quite strong (Bogin and Beydoun, 2007; Deurenberg et al., 1999; Frisancho, 2007).

TABLE 5. Estimates of women's body composition in multiple linear regression

		Model 1		Model 2		Model 3		Model 4	
		B (SE)	P	B (SE)	P	B (SE)	P	B (SE)	P
%BF[a]	Constant	25.085 (3.535)	<0.001	19.063 (15.851)	0.235	35.571 (25.574)	0.170	50.893 (25.325)	0.050
	BMI[b]	0.585 (0.119)	<0.001	0.718 (0.532)	0.183	0.639 (0.125)	<0.001	0.670 (0.117)	<0.001
	Stunted[c,d]			2.762 (1.098)	0.015			2.635 (1.138)	0.025
	BMI × Stunted			−0.650 (0.288)	0.823				
	SHR[e]					−0.231 (0.490)	0.639	-0.569 (0.492)	0.253
	BMI × SHR					0.247 (0.110)	0.030	0.167 (0.111)	0.141
	R^2 adj	0.309		0.364		0.361		0.413	
WC (cm)[f]	Constant	34.763 (3.949)	<0.001	11.591 (18.513)	0.534	95.508 (28.838)	0.022	89.306 (28.561)	0.003
	BMI	1.815 (0.133)	<0.001	2.594 (0.621)	0.983	1.890 (0.137)	<0.001	1.905 (0.139)	<0.001
	Stunted			0.027 (1.282)	0.983			0.550 (1.288)	0.671
	BMI × Stunted			−0.432 (0.336)	0.205				
	SHR					−1.171 (0.554)	0.040	−1.075 (0.557)	0.059
	BMI × SHR					0.137 (0.125)	0.277		
	R^2 adj	0.781		0.780		0.793		0.789	

[a]%BF, percent body fat calculated from an bioelectric impedance equation specific to American Indian women (Stolarczyk et al., 1994).
[b]BMI, body mass index.
[c]Stunting for adult women defined as stature below 150 cm.
[d]Nonstunted was set as the reference.
[e]SHR, sitting height ratio.
[f]WC, waist circumference.

TABLE 6. Estimates of women's upper arm composition in multiple linear regression

		Model 1		Model 2		Model 3		Model 4	
		B (SE)	*P*	*B* (SE)	*P*	*B* (SE)	*P*	*B* (SE)	*P*
UMA (cm^2)[a]	Constant	15.097 (6.964)	0.035	44.382 (32.831)	0.183	33.167 (52.516)	0.531	20.580 (52.136)	0.695
	BMI[b]	0.733 (0.234)	0.003	−0.277 (1.101)	0.802	0.720 (0.249)	0.006	0.749 (0.253)	0.005
	Stunted[c,d]			0.990 (0.274)	0.665			1.086 (2.352)	0.646
	BMI × Stunted			0.563 (0.596)	0.945				
	SHR[e]					−0.323 (1.010)	0.751	−0.127 (1.017)	0.901
	BMI × SHR					−0.277 (0.227)	0.229		
	R^2 adj	0.145		0.129		0.136		0.113	
AFA (cm^2)[f]	Constant	−32.817 (2.920)	0.001	−41.949 (40.278)	0.303	70.103 (65.531)	0.290	54.395 (62.402)	0.388
	BMI	2.408 (0.296)	<0.001	2.884 (1.351)	0.038	2.577 (0.310)	<0.001	2.509 (0.303)	<0.001
	Stunted			−5.642 (2.790)	0.049			−4.743 (2.815)	0.092
	BMI × Stunted			−0.282 (0.731)	0.702				
	SHR					−2.000 (1.260)	0.119	−1.600 (1.217)	0.195
	BMI × SHR					0.056 (0.284)	0.843		
	R2 adj	0.556		0.575		0.563		0.588	
AFI[g]	Constant	19.883 (8.751)	0.027	9.628 (40.681)	0.814	52.259 (65.329)	0.428	59.163 (63.916)	0.359
	BMI	1.041 (0.294)	0.001	1.496 (1.364)	0.278	1.148 (0.309)	0.001	1.075 (0.311)	0.001
	Stunted			−4.341 (2.818)	0.130			−4.002 (2.883)	0.171
	BMI × Stunted			−0.266 (0.739)	0.720				
	SHR					−0.672 (1.256)	0.595	−0.695 (1.246)	0.580
	BMI × SHR					0.373 (0.283)	0.194		
	R^2 adj	0.181		0.190		0.190		0.193	

[a]UMA, upper arm muscle area (Frisancho, 2008).
[b]BMI, body mass index.
[c]Stunting for adult women defined as stature below 150 cm.
[d]Nonstunted was set as the reference.
[e]SHR, sitting height ratio.
[f]AFA, arm fat area (Frisancho, 2008).
[g]AFI, arm fat index, percent of the upper arm that is fat (Frisancho, 2008).

According to the literature, SHR does appear to significantly impact BMI and can do so quite substantially in certain groups; however, it may be a relatively small effect when considered alongside other factors. A relatively small sample, with limited variability in both total stature and SHR, such as the one used in this study would have less power to detect these relatively small differences. The overall short stature of this population suggests that all members of the population could have experienced chronically poor conditions regardless of their stunting status. Even the tall individuals in this sample may be at risk for the negative health outcomes associated with short stature since the relationship between stature and mortality is linear (Song and Sung, 2008). The apparent environmentally imposed limit on stature may be over-riding any impact of stunting or body proportions that this study was attempting to investigate. A sample with more variation in stature may be more likely to determine the impact of stunting on BMI. This study can only conclude that in a small, very short sample with limited variability in linear growth, dividing the group into stunted and nonstunted does not influence the use of BMI as a predictor of adiposity indicators. Also BMI alone is not sufficient to adequately estimate adiposity indicators, particularly in a population which is chronically undernourished (stunted). Using BMI alone would give a skewed picture of the overall nutritional status of a dual burdened population as the levels of adiposity are high but the nutrition is not of high enough quality for adequate growth, resulting in short stature.

The small sample and limited variability in stature and SHR greatly reduce the power of this study to find statistical differences. Studies involving a larger sample with greater variability are much more likely to detect statistical differences, particularly if differences actually exist. Future studies may also measure chronic disease risk factors, as well as adiposity indicators to obtain a better understanding of the relationship between stunting, body proportions, BMI, and chronic disease. Obesity-related chronic diseases are becoming a very large health concern in developing countries, particularly middle income countries such as Mexico, which are still grappling with undernutrition. More fully understanding the relationship between over and undernutrition will help inform greatly needed public health policies.

CONCLUSIONS

In conclusion, the samples of women and children studied have high levels of adiposity and short stature with low variation in stature. This small study found that BMI is appropriate for use to estimate adiposity indicators in this sample of 7–9-year-old urban Mayan children. However, it is recommended that BMI be used in conjunction with other measures such as stature and waist circumference to obtain a more complete estimation of a child's nutritional status. Conversely, BMI is not recommended for use in this sample of adult urban Mayan women. WC may be of value for use in these women to estimate their chronic disease risk, though its validity has not yet been established for this population. The ability of BMI to predict adiposity indicators is not impacted by stunting status or SHR in this sample.

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