

*Original Research Article***Influence of Maternal Stature, Pregnancy Age, and Infant Birth Weight on Growth During Childhood in Yucatan, Mexico: A Test of the Intergenerational Effects Hypothesis**MARIA INÈS VARELA-SILVA,<sup>1\*</sup> HUGO AZCORRA,<sup>2</sup> FEDERICO DICKINSON,<sup>2</sup> BARRY BOGIN,<sup>1</sup> AND A. R. FRISANCHO<sup>3</sup><sup>1</sup>Loughborough University, Department of Human Sciences, Loughborough, Leicestershire LE11 3TU, United Kingdom<sup>2</sup>Centro de Investigación y de Estudios Avanzados (Unidad Mérida), 97310 Mérida, Yucatan, México<sup>3</sup>Department of Anthropology, University of Michigan, Ann Arbor, Michigan 48109-1092*This article was presented at the 2008 AAPA meeting in a symposium in honor of A. Roberto Frisancho, on the occasion of his retirement from the Department of Anthropology of the University of Michigan*

**ABSTRACT** In developing nations, obesity has increased dramatically in the last decade, but a high prevalence of stunting still coexists. The intergenerational influences hypothesis (IIH) is one explanation for this. We test the IIH regarding variation in maternal stature, mother's age at pregnancy, and infant birth weight in relation to risk for overweight and stunting in 206 Maya children (4–6 years old) from Mérida, Yucatan, Mexico. The Maya children are compared with growth references (Frisancho [2008]: *Anthropometric Standards: An Interactive Nutritional Reference of Body Size and Body Composition for Children and Adults*. Ann Arbor, MI: The University of Michigan Press. 335 pp) for height, weight, and body mass index (BMI). Almost 70% of the mothers are shorter than 150 cm. Mothers' height and child's birth weight predict overweight. Children with a mother shorter than 150 cm are less than half as likely (OR = 0.44) to be overweight compared to children whose mothers are equal to or taller than 150 cm. Children with birth weights below 3,000 g are only a third as likely to be overweight (OR = 0.28) than their peers within the range of normal birth weight (3,000–3,500 g). Sex of the child, mother's height, and birth weight predict stunting. Girls are only 40% as likely as boys to be stunted. Children with a mother below 150 cm are 3.6 times more likely of being stunted. Children with birth weights below 3000 g are over 3 times more likely to be stunted relative to children with birth weights within the normal range. Mother's age at pregnancy is not a predictor of overweight or stunting. Our findings conform the IIH and with similar studies of populations undergoing nutritional/epidemiological transitions from traditional to globalized lifestyles. *Am. J. Hum. Biol.* 21:657–663, 2009. © 2009 Wiley-Liss, Inc.

In developing nations, the epidemic of obesity has increased dramatically in the last decade (de Onis and Blossner, 2000; Kosti and Panagiotakos, 2006; Martorell et al., 2000; Popkin and Doak, 1998). However, developing nations are also still struggling with high prevalence of stunting (low height-for-age), an indicator of chronic malnutrition (Black et al., 2008; de Onis et al., 2000; Popkin et al., 1996). Together obesity and stunting pose an exponential burden on the health of the current generation in developing countries. Women who suffered from malnutrition during their own growth process tend to end up with short stature in adulthood. These women tend to give birth to small babies (Cawley et al., 1954) who are at higher risk for overweight and other diseases later in life (Barker, 2007; Drake and Walker, 2004; Gluckman et al., 2007; Wells, 2007). The relationship between birth weight and later obesity seems to show a U-shaped relationship, in that neonates at both extremes of the birth weight spectrum tend to have a higher likelihood of becoming overweight (Taylor and Poston, 2007). Other studies show a relationship between short-stature of mothers and overweight and/or stunting during childhood (Zottarelli et al., 2007). Mother's age at pregnancy can also affect birth size and weight (Wallace et al., 2004) as very young mothers may have not finished their own growing process and will compete with the fetus for energetic resources.

The intergenerational influences hypothesis (IIH) was proposed by Emanuel (1986) as, "... those factors, conditions, exposures and environments experienced by one generation that relate to the health, growth and develop-

ment of the next generation." The intergenerational effects hypothesis includes "fetal programming," "perinatal adaptive responses," "life history trade-offs," "developmental adaptations," and related concepts in the literature (Barker, 1990, 1995; Bogin et al., 2007; Gluckman and Hanson, 2004; Kuzawa, 2007). The original IIH was proposed to account for the persistence of low birth weight across generations.

In the context of this paper, the IIH relates to the existence of a nongenomic mechanism in which malnutrition of the mother during her fetal and early postnatal development, as well as poor birth outcomes of the offspring, will have health consequences for her offspring, especially low birth weight and obesity (Drake and Walker, 2004; Kuzawa and Pike, 2005; Ravelli et al., 1976). The quality of the intrauterine and early postnatal environment will result in fetus/infant metabolic adjustments, both beneficial and harmful. These variations will influence the growth, development, and health of individuals for the rest of their lives. In the case of women, whose reproductive systems are largely developed during their own fetal period, these variations will also influence their offspring. It may take three or more generations of development

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under good health conditions to completely override the past history of poor health (Emanuel, 1986; Price and Coe, 2000).

The present analysis focuses on a Maya population from the Yucatan Peninsula, Mexico. The Maya have a long history of social, economic, and political repression at the hands of European colonists and, more recently, from the political regimes of Mexico and Central America (Montejo, 1999). In addition, the Maya population of Mexico is confronting the effects of the nutrition transition, shifting from the consumption of traditional foods to westernized fast foods that are high in energy but nutritionally poor (Leatherman and Goodman, 2005). This nutritional transition, along with the legacy of poverty and low social conditions, increase the risk for overweight and associated diseases, stunting, and overall impaired growth (Fernald, 2007; Gurri et al., 2001).

Merida is located in the northwestern part of the State of Yucatan, less than 40 km away from the Gulf of Mexico (INEGI, 2007). The decline in the sisal industry in the 1990s left thousands of rural Mayan unemployed and drove them toward Merida in search of work. This economic and population change, combined with the overall unstable economy of the rural areas in the Yucatan, caused a sharp demographic growth of precarious neighborhoods, mainly in the southern portion of the city of Merida (Garcia, 2000). The south part of Merida has the lowest income and the poorest infrastructures and urban services in the entire city (Dickinson et al., 1999). By 2000, Merida had grown to cover 17,280 ha (Bolio, 2000), and according to the most recent census, Merida has currently about 734,153 inhabitants (INEGI, 2006). From these, an estimated of 230,000 are Maya (Lewin and Guzman, 2005).

The Maya of Mexico and Central America are one of the shortest populations and were once considered to be genetically adapted "pygmies" of Latin America (Diamond, 1992). However, research with Maya immigrants to the United States finds that Maya-Americans ages 5–12 years old are 11.54 cm taller than their sedente counterparts (Bogin and Loucky, 1997; Bogin et al., 2002; Smith et al., 2002). The increase in stature occurred within one generation of people, negating the hypothesis that the extreme short stature of Maya populations is largely of genetic origin. Despite the fact that the Maya-American children are, on average, growing taller, 11.5% are clinically stunted and almost 50% of the children are classified as overweight or obese based on the age and gender-specific BMI percentiles from the Centers for Disease Control (CDC). Elsewhere, we have hypothesized that the expression of such high rates of overweight in the Maya-American children is a case of intergenerational effects of poverty, malnutrition, and disease in past generations causing pathological metabolic physiology in the current generation of immigrants (Varela-Silva et al., 2007).

The objective of this paper is to test the IHH in a sample of 4- to 6-year-old Maya children from Mérida, Yucatan, Mexico. Specifically, we examine the impact of variation in maternal stature, pregnancy age, and infant birth weight in relation to risk for overweight and stunting in the children.

## MATERIALS AND METHODS

Our sample is composed of 206 Maya children (86 boys and 120 girls), 4–6 years of age, living in Mérida, Yucatan,

Mexico. The selection criterion for classification as Maya was that, at least, one of the parent's surnames was Maya. Two hundred and one mothers of these children were measured for height and 191 reported age at pregnancy and birth weight of their children. Most of the mothers are young women with few children. When asked about their child's birth weight, they usually replied with an exact number, such as 3.35 kg. We take the lack of rounding or heaping as evidence of a true recollection of birth weight. Most births occurred in hospital or clinics of the Mexican Social Security Institute. Such clinics exist even in the rural areas from which most of the interviewed mothers originated. According to our field experience (reported by author HA), when a child is delivered at home with the assistance of a midwife, the mother takes the baby to a clinic where the newborn will be weighed and examined. Given this ethnographic evidence, we feel that the reported birth weights are of sufficient quality for use in our analyses.

The measurements took place in 2006 in a *colonia* (neighborhood) in the southern part of Mérida characterized by low socioeconomic status and a high proportion of immigrants from rural areas. Height (cm), weight (kg), and body mass index [BMI = weight (kg)/height (m<sup>2</sup>)] of the children and height of the mothers were recorded using standardized techniques (Lohman et al., 1988). The growth reference values published by Frisancho (2008) were used to categorize the sample. These growth references provide values from the NHANES III databases (comprehensive references, covering representative samples of American non-Hispanic Whites, non-Hispanic Blacks and Hispanics, ages 2–90 years of age), as well as the reference values from the Centers for Disease Control and Prevention (2–20 years of age) and the growth standards from the World Health Organization (birth to 5 years of age). In this paper, we selected the NHANES III comprehensive references. According to Frisancho (2008), stunting, or chronic malnutrition, is defined as having a *z*-score value of height-for-age equal or below  $-1.650$ . Overweight is defined as having a BMI equal or above the 85th percentile (or a *z*-score between  $+1.036$  and  $+1.640$ ).

The sample of children was divided by sex and age groups. We present descriptive statistics and then sample *t*-tests to compare the mean values of the standard deviation-scores against the reference values. Backward logistic regression was used to build a model of variables influencing the risk for overweight (0 = no, 1 = yes) and stunting (0 = no, 1 = yes) in the children. Both models include the following variables: child's sex (0 = boy, 1 = girl), child's age (decimal years), child's birth weight (0 = between 3,000 and 3,500 g, 1 = below 3,000 g, 2 = above 3,500 g), mother's height below 150 cm (0 = no, 1 = yes), and mother's age at pregnancy (years). The level of significance was set at  $\alpha = 0.05$  in all analyses.

## RESULTS

### *Descriptive results and comparisons against the references*

In Table 1, we present the descriptive statistics for height, weight, BMI, and birth weight of the children, as well as mother's age at pregnancy and mother's height.

In Table 2, we present summary indicators for nutritional status, specifically, percentages of stunting, overweight and stunting + overweight of the children, and percentage of mothers below the 5th percentile for height

TABLE 1. Descriptive statistics of child's anthropometry, birth outcomes, and maternal stature (mean ± SD)

	Age	N	Height (cm)	Weight (kg)	BMI (kg/m <sup>2</sup> )	Birth weight (g) <sup>a</sup>	Mother's age at pregnancy (years) <sup>b</sup>	Mother's height (cm) <sup>c</sup>
Boys	4	26	101.39 ± 4.75	17.81 ± 4.48	17.14 ± 2.88	3,258 ± 503.25	23.15 ± 6.16	147.93 ± 4.92
	5	28	107.31 ± 5.36	18.35 ± 2.98	15.83 ± 1.33	3,270 ± 499.10	24.89 ± 6.12	148.06 ± 6.37
	6	32	112.98 ± 5.45	23.41 ± 5.59	18.14 ± 2.92	3,244 ± 435.76	26.90 ± 7.07	147.10 ± 4.49
	Total	86	107.63 ± 7.02	20.07 ± 5.18	17.09 ± 2.66	3,257 ± 472.01	25.09 ± 6.60	147.68 ± 5.26
Girls	4	27	102.35 ± 4.57	17.82 ± 3.17	16.91 ± 2.05	3,151 ± 416.93	25.00 ± 5.90	148.34 ± 4.96
	5	52	105.23 ± 4.17	18.00 ± 2.64	16.70 ± 2.04	3,160 ± 488.54	24.96 ± 6.54	147.22 ± 5.22
	6	41	112.07 ± 4.24	21.19 ± 3.36	16.81 ± 2.03	3,138 ± 541.74	24.98 ± 5.49	145.38 ± 5.90
	Total	120	106.92 ± 5.76	19.05 ± 3.37	16.78 ± 2.02	3,151 ± 488.00	24.98 ± 6.01	146.85 ± 5.48
Total		206	107.22 ± 6.31	19.48 ± 4.24	16.91 ± 2.31	3,195 ± 483.10	25.02 ± 6.24	147.19 ± 5.39

<sup>a</sup>Fifteen missing cases.

<sup>b</sup>One missing case.

<sup>c</sup>Five missing cases.

TABLE 2. Nutritional status of the children and the mothers

	Stunting (%) <sup>a</sup>	Overweight (%) <sup>b</sup>	Stunted and overweight (%)	Height below 150 cm (%)	Height equal to or above 150 cm (%)
Children	21.8	33	2.4	—	—
Mothers	70.9	—	—	69.4	28.2

<sup>a</sup>Height-for-age below 5th percentile (Frisancho, 2008).

<sup>b</sup>BMI-for-age above 85th percentile (Frisancho, 2008).

Anthropometry - boys

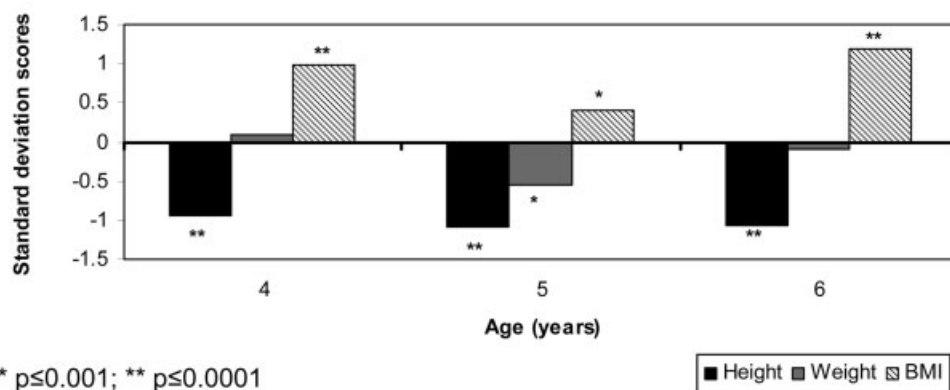


Fig. 1. Standard deviation-scores for height, weight, and BMI, by age group: boys. One sample *t*-test, comparison against reference values (Frisancho, 2008).

Anthropometry - girls

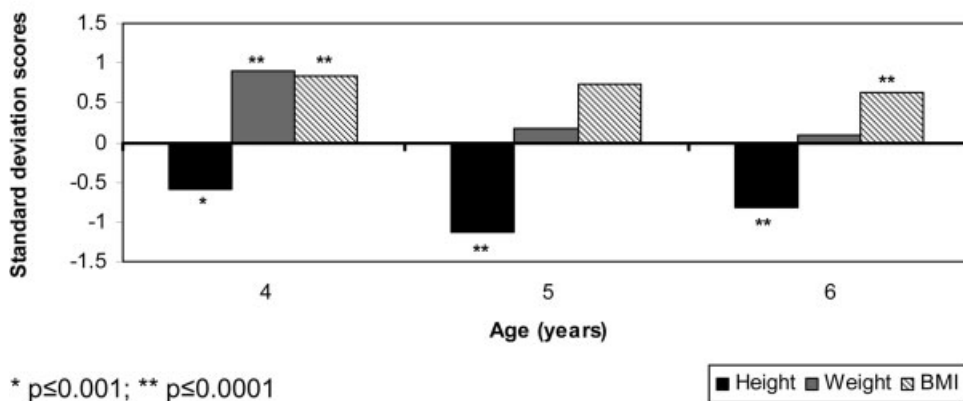


Fig. 2. Standard deviation-scores for height, weight, and BMI, by age group: girls. One sample *t*-test, comparison against reference values (Frisancho, 2008).

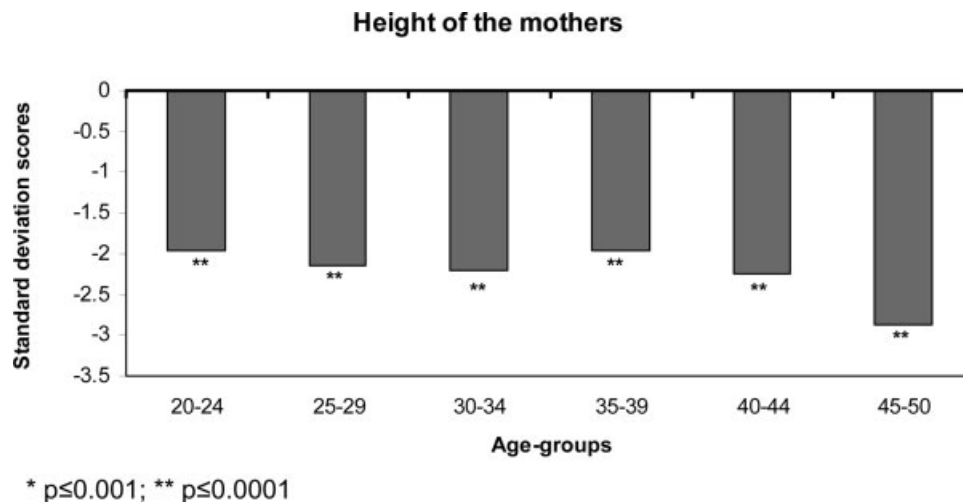


Fig. 3. Standard deviation-scores for mothers' height, by age group. One sample *t*-test, comparison against reference values (Frisancho, 2008).

TABLE 3. Odds ratio (OR) and 95% confidence intervals for the predictors of Maya children having a BMI equal or above the 85th percentile (overweight) versus having a BMI below the 85th percentile (not overweight)

Variables	OR	95% CI	P-value
Mother's height			
Equal or above 150 cm	1	Reference	–
Below 150 cm	0.44	0.22–0.88	0.02
Birth weight			
3,000–3,500 g	1	Reference	–
Below 3,000 g	0.28	0.12–0.65	0.003
Above 3,500 g	0.87	0.39–1.92	ns

as well as the percentage of mothers whose height is below or above 150 cm.

Almost 22% of the children are stunted, and 33% are overweight. The combination of being stunted and overweight (dual-burden individuals) occurs in 2.4% of the children. Most of the mothers are very short. More than 70% have standard deviation scores for height below the 5th percentile and 69.4% are below 150 cm in height.

When compared with the reference values, the mean height-for-age *z*-scores (HAZ) for boys are  $-0.95$  at age 4,  $-1.09$  at age 5, and  $-1.07$  at age 6. Weight-for-age *z*-scores (WAZ) are  $0.09$  at age 4,  $-0.54$  at age 5, and  $-0.09$  at age 6. *z*-scores of BMI (ZBMI) are  $0.99$  at age 4,  $0.40$  at age 5, and  $1.19$  at age 6 (see Fig. 1). At all ages, the boys' HAZs are significantly lower than the reference (i.e. 50th centile) US boys. In contrast, WAZs at ages 4 and 6 do not differ from the reference value, but at age 5 the boys are significantly lighter than their US peers. The ZBMI are significantly higher than the references at all ages.

When compared with the reference values, HAZs for girls are, on average,  $-0.59$  at age 4,  $-1.13$  at age 5, and  $-0.82$  at age 6, all significantly lower than the references. WAZs are  $0.90$  at age 4,  $-0.17$  at age 5, and  $0.09$  at age 6 significantly different from the references at age 4 only. ZBMI scores are  $0.83$  at age 4,  $0.73$  at age 5, and  $0.64$  at age 6, significantly higher than the references at all ages (see Fig. 2).

Mother's HAZs (Mean =  $-2.13 \pm 0.84$ ) are significantly lower than the references, below  $-2.0$  *z*-scores in all age-groups (see Fig. 3).

TABLE 4. Odds ratio (OR) and 95% confidence intervals for the predictors of Maya children being stunted versus not stunted

Variables	OR	95% CI	P-value
Child's sex			
Boy	1	Reference	–
Girl	0.40	0.19–0.85	0.02
Mother's height			
Equal or above 150 cm	1	Reference	–
Below 150 cm	3.6	1.31–9.85	0.01
Birth weight			
3,000–3,500 g	1	Reference	–
Below 3,000 g	3.45	1.53–7.77	0.003
Above 3,500 g	0.34	0.09–1.23	ns

#### Predictors of overweight and stunting

The results of the backward logistic regression analyses are presented as odds ratios and 95% confidence intervals (Tables 3 and 4). In Table 3, we compare overweight children with nonoverweight children. Mothers' height and child's birth weight are significant predictors of overweight. Maya children whose mothers' height is below 150 cm are less than half as likely (OR = 0.44) to be overweight, compared to children whose mothers' height is above 150 cm. Children with birth weights below 3,000 g are only a third as likely to be overweight (OR = 0.28) than their peers within the range of normal birth weight (3,000–3,500 g). Sex of the child, age of the child, and mother's age at pregnancy do not predict overweight in this sample.

In Table 4, we compare stunted children with non-stunted children. Sex of the child, mother's height, and child's birth weight are significant predictors of stunting. Girls are only 40% as likely (OR = 0.4) as boys to be stunted. Maya children whose mothers' height is below 150 cm are 3.6 times more likely to be stunted than children whose mothers' height is above 150 cm. Children with birth weights below 3,000 g are over three times more likely to be stunted than children within the range of normal birth weight (3,000–3,500 g). Mother's age at pregnancy does not predict stunting in this sample.

## DISCUSSION

Nutrition transition, rural-to-urban migration, urbanization of the rural communities, and reduction in the levels of physical activity have been pointed out as the major factors for the epidemic of obesity in wealthier, developed countries, where overweight and obesity are associated with normal-to-tall stature-for-age (Bauman and Craig, 2005; Brody, 2002; Goran and Treuth, 2001; Popkin, 2004) and where the prevalence of undernutrition is very low (SNC, 2004). However, these factors do not fully explain the epidemic of overweight in the poorer, developing countries where the prevalence of stunting is still very high. Other factors, such as metabolic pathways, that have been adjusted for periods of famine and/or low caloric intake may be involved. Studies conducted among undernourished groups have shown that specific metabolic pathways are activated in individuals who suffered gestational or infantile nutritional deprivation (Sawaya et al., 2004).

There is also an intergenerational effect, in that women who suffered from malnutrition during their own growth process give birth to metabolically compromised neonates at risk for overweight later in life (Drake and Walker, 2004; Gluckman et al., 2007; Wells, 2007). These individuals tend to shift toward a preferential metabolic use of carbohydrates instead of fat (Barac-Nieto et al., 1979; Spurr and Reina, 1988; Walker et al., 1991). This shift leads to an increased deposition of body fat that will facilitate the onset of overweight later in life (Caballero, 2005).

Several studies (Dulloo, 1997; Dulloo and Girardier, 1990; Felber et al., 1981; Hoffman et al., 2000a,b) show that previously malnourished individuals preferentially oxidize carbohydrates for their energy needs and tend to store fat. Studies conducted by Malcolm (1970), Barac-Nieto et al. (1979), and Spurr and Reina (1988) show that in nutritionally deprived children the effects of food supplementations increase the amount of body fat and muscle mass, but the children did not use the extra energy to grow in length. The processes of conserving energy when life-threatening undernutrition is present lead to what Keys et al. (1950) called "poststarvation obesity," based on the results of the Minnesota semistarvation experimental studies.

Overall, the Maya children of the present sample conform to the patterns seen in the studies reviewed above. The Maya children are significantly shorter than the references and the prevalence of stunting is 21.8%. These Maya children also present significantly higher BMI values than the references, with 33% of them being overweight. We are aware that BMI is an imperfect proxy for body fatness, overweight, and obesity, especially in children and adults who have body proportion phenotypes reflecting generations of chronic malnutrition and disease. The work with Maya immigrant families to the United States (Bogin and Loucky, 1997; Bogin et al., 2002; Smith et al., 2002) shows that the Maya children have significantly greater BMI than American reference data, but also relatively short legs for their stature. This phenotype may inflate the value of the BMI, irrespective of the amount of body fat, due to fundamental biometric relationships of body proportions. The head, chest, and abdomen of the body (the "sitting height") account for a greater proportion of total body mass than the arms and legs. Accordingly, if all other aspects of body composition are equal, then when comparing two people of equal sitting

height, the BMI will be greater in the person with relatively shorter legs. Furthermore, BMI does not distinguish between fat and lean tissue. It is possible, therefore, that the BMI of the Mexican-Maya children of the present study is affected by both body proportion and body composition differences compared with the reference data.

Despite these caveats, the results reported here concur with previous studies showing that Latin American children migrating from rural to urban environments (Bogin and Loucky, 1997) or in nutritional/epidemiological transition (Malina et al., 2008) are at risk for overweight and obesity, as measured by BMI and skinfolds. Our findings also follow other studies showing that despite positive improvements in height for the majority of children, stunting continues to be a problem for many individuals (Popkin et al., 1996).

Mother's height and birth weight are significant predictors of child's overweight. A mother being shorter than 150 cm lowers the risk for child overweight. This may at first seem to contradict the IIH; however, it is a pattern found in some studies in developing countries (Groeneveld et al., 2007; Monteiro et al., 2004; Van Hook and Balistreri, 2007). A possible explanation for this finding is that the offspring of these short mothers are slow growing before and after birth. Previous research finds that slow growth prior to birth, evidenced by relatively lower birth weight, followed by rapid growth after birth is a risk factor for later overweight (Ong, 2007; Ong et al., 2000).

The effect of mother's height does not seem to be associated with socioeconomic status (SES). Unpublished results from co-author HA using the same sample show no differences in SES between mothers below and above 150 cm when using different variables, such as family income, money spent on feeding, and characteristics of the household. This means that there is no evidence that taller women from this sample belong to families with a relatively high SES, who might offer more food to their children.

Maya children with a birth weight below 3,000 g seem to be protected against overweight. Monteiro et al. (2003) also found a linear relationship between birth weight and later obesity in Brazil, meaning that lower birth weight babies were less likely to be overweight later in life. A growing body of research finds that lower birth weight babies who show rapid postpartum increases in body size do have a greater risk for overweight at later ages (Ibáñez et al., 2006; Monteiro and Victora, 2005; Stettler et al., 2005). It seems likely that the lower birth weight Maya children studied here did not have a rapid period of growth soon after birth and, instead, remained relatively small throughout their lives.

The sex of the child, mother's height, and birth weight are predictors of stunting. Being a girl protects from stunting and this may be explained by the "buffering hypothesis" (Stinson, 1985) in which the growth of girls seems to be less susceptible to adverse environmental conditions.

As seen above, the mothers in our study are very small, with almost 70% below the 5th percentile for height-for-age and 69.4% with a height value below 150 cm. The increased risk for stunting of children with mothers below 150 cm is support for the IIH. Mother's whose own growth was compromised pass on similar risks to their offspring. A birth weight below 3,000 g increases the odds of stunting during childhood. This indicates that the intergenera-

tional influences are at work before birth. Our findings agree with the results of Zottarelli et al. (2007) in Egypt in which it was also found that children were at a greater risk of stunting if their mothers' height were below 150 cm.

The next phase of our research is to conduct metabolic studies of the Maya children, and their mothers, to test the IHH in a more direct fashion. Pending the success of funding proposals under review at the time of this writing, we will carry-out indirect calorimetry to assess nutritional substrate utilization and rate of fat versus carbohydrate oxidation. With these new data, we may be better able to understand the influences of maternal stature, infant birth weight, and sex on risk for childhood stunting and overweight.

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