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6 authors, including:

Adriana Vázquez-Vázquez
University College London

Ina Falfán
Institute of Ecology INECOL

Federico Dickinson
Center for Research and Advanced Studies of…

Original Research Article

Effects of Maya Ancestry and Environmental Variables on Knee Height and Body Proportionality in Growing Individuals in Merida, Yucatan

ADRIANA VÁZQUEZ-VÁZQUEZ,[1]* HUGO AZCORRA,[2] INA FALFÁN,[1] JORGE ARGÁEŹ,[3]
DIÓDORA KANTUN,[3] AND FEDERICO DICKINSON[1]
[1]*Department of Human Ecology, Cinvestav-Merida, Yucatan, Mexico*
[2]*School of Sport, Exercise and Health Sciences, University of Loughborough, Loughborough, United Kingdom*
[3]*Faculty of Mathematics, Autonomous University of Yucatan, Merida, Yucatan, Mexico*

ABSTRACT: Objective: Identify the biological, social, and economic conditions influencing the knee height/stature index (KHSI) in growing individuals of Maya ancestry in the city of Merida, Yucatan, Mexico.

Methods: The hypothesis was that KHSI values would be lower in subjects with two Maya surnames. This was tested by analyzing the effect of a series of environmental, biological, and socioeconomic variables on stature and knee height (KH). Data were collected from 2008 to 2009 from 841 individuals (444 girls), 9 to 17 years of age, in Merida, Yucatan, Mexico. Ancestry was used as a proxy for genetics, and based on number of Maya surnames (2, 1, or none). The KHSI was calculated for all individuals. Multiple regression models were run to identify the variables that best explained variation in stature, KH, and KHSI.

Results: Ancestry negatively ($P < 0.05$) affected stature, but birth weight, crowding index, and mother's education level (MEL) were more significant ($P < 0.01$). Ancestry had no effect on KH and KHSI values, but birth weight and MEL had a significant effect. Individuals who had grown up in an adverse environment, in terms of MEL, had higher KHSI values. Apparently, lower leg length was proportionally longer than thigh length in the sample.

Conclusions: Growth measurements were more responsive to the studied environmental variables than to ancestry-related genetic conditions. Genetic predisposition is, therefore, not the primary cause of short stature in this sample of Yucatec Mayas. Am. J. Hum. Biol. 25:586–593, 2013.

Research on human physical growth uses different methods for identification and analysis of environmental and biological factors, such as education level and genetic group, that can directly and/or indirectly intervene in body growth and proportionality.

The Maya of Mexico and Central America are one of the shortest human populations on record. Indeed, they were once erroneously thought to be genetically adapted pigmies (Diamond, 1992) due to lower growth rates in Maya children than in those of other human groups (Steggerda, 1941, 1977). Research done over the last 30 years does not support this conclusion. Further research is needed to clarify the relationship between growth in the Maya population and the factors affecting it. Current body shape among the Yucatec Maya more probably depends on social, economic, political, and ecological changes, as well as genetics. These changes would have begun during European colonization of the Americas, or earlier, and are still manifest in today's Maya population. This study objective was to identify environmental, biological, social, and economic variables that may influence body growth and proportionality of individuals of Maya ancestry using stature, knee height (KH), and the KH/stature index (KHSI) as an indicator of body proportionality in data from a sample of growing individuals in Merida, Yucatan. As far as we know, this is the first study focused on this issue in the population of Yucatan, and constitutes a valuable addition to the literature addressing this phenomenon.

THEORETICAL FRAMEWORK

The apparent deficit in physical growth among human populations in Yucatan state, Mexico, during the past 2 centuries is documented in the literature (Azcorra et al., 2010; Cervera, 1994; Cervera et al., 1995; Dickinson, 1997; Dickinson et al., 1989, 1991, 2003; Gurri and Balam, 1992; McCullough, 1982; Siniarska and Wolanski, 1999a; Steggerda, 1941, 1977; Varela-Silva et al., 2009). Much of the literature on body shape among the contemporary Maya indicates them to have short stature with long arms relative to stature, brachycephaly, short lower limbs, and a long trunk relative to height (Serrano Sánchez, 1997; Steggerda, 1941, 1977).

Determining if the low stature and prevailing body proportion (i.e., lower limbs to height ratio) of the current Maya population originates solely in genetics, or a combination of life conditions and genetics, requires data on the effects that ecological, social, and economic factors have on somatic characteristics (Dickinson et al., 1991; Kelley, 1991; Murguía, 1981; Siniarska and Wolanski, 1999a, 2005; Wolanski and Siniarska, 2000; Wolanski et al., 1993). Stated more generally, more information is needed on how the environment affects human corporality (Dickinson, 1983), stature and leg length are good indicators of an individual's life condition during growth (Bogin, 1999; Frisancho, 1990; Gurri and Dickinson, 1990; Leitch, 1951; Ramos, 1987). A number of kinds of factors affect human growth: (1) environmental, such as crowding, and access to piped water and toilets (Bogin, 1999; Ulijaszek et al., 1998); (2) biological, such as birth weight (Herngreen et al., 1994; Ulijaszek et al., 1998); (3) ancestry, that is, an

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*Correspondence to: Adriana Vázquez-Vázquez, E-mail: apvazquezv@gmail.com

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individual's link to her/his ancestors, as a proxy for genetics; and (4) social and economic, such as head of household's employment status and income (Bogin, 1991, 1999; Bogin and Keep, 1999; Frisancho et al., 2001; Siniarska and Wolanski, 1999a; Ulijaszek et al., 1998).

Reported data on stature among adult Yucatec Maya suggest a general increase over the last 150 years. McCullough (1982) reported no change in overall adult height in men born between 1860 and 1933. In contrast, Siniarska and Wolanski (1999b) reported a positive change by decade of 1.15 cm in men and 1.55 cm in women between 1928 and 1976. As a consequence, adult height increased in this period from 155 to 160 cm in men and from 143 to 148 cm in women. Maya youth (12–17 years of age) from Merida studied in 1993 (Wolanski, 1994) were 4 cm taller than those from Ticul studied in 1976 (McCullough and McCullough, 1984), and 10 cm taller than those from rural areas studied in 1936 (Steggerda, 1941, 1977). This increase in height may be due to improvements in food production and the health system (Siniarska and Wolanski, 1999b).

Like all mammals, humans follow a cephalocaudal growth pattern, which determines body proportionality. During early development, cephalic growth is still quite rapid, but growth of the lower extremities begins to accelerate. In the face of adverse conditions such as lack of sufficient food or social and economic difficulties, lower limb growth slows, leading to lower heights due to shorter lower limbs (Bogin and Varela Silva, 2010). This is known as distorted body proportionality (Frisancho et al., 2001; Leitch, 1951). Lower leg length, that is, the length from the knee to the tibia/fibula and heel bones, exhibits more variation in growth than the femur. It, therefore, better expresses any environmental effects on growth and overall height (Anderson et al., 1963; Del Ángel and Serrano, 1991; Floyd, 2008; Meadows and Jantz, 1995; Meadows Jantz and Jantz, 1999).

Very little data exist on KH in relation to stature, a shortage particularly acute for Maya populations. This limits understanding of this group's body shape and proportionality as well as any efforts to address developmental problems specific to the Maya. The hypothesis tested here is if KHSI values are lower (i.e., short lower limbs in relation to height) in individuals with two Maya surnames compared to those with just one or no Maya surname.

METHODOLOGY AND TECHNIQUES

The analyzed data are from a semi-longitudinal study of individuals 9–17 years of age living in the city of Merida. Only data from the initial measurement of stature and KH (including the tibia, fibula and heel bones) was used in the analysis. The KHSI was calculated using the formula

$$\text{KHSI} = \frac{\text{knee height (cm)}}{\text{stature (cm)}} \text{x} 100$$

Other data collected included birth weight, surname origin, crowding index, piped water access, toilet access, school type, reported family income, head of household employment status, and mother's education level (MEL) (Table 1).

TABLE 1. Variables included in this study

Variable	Variable type
Stature (cm)	Continuous
KH (cm)	Continuous
KHSI (%)	Continuous
Birth weight (kg)	Continuous
Surnames' origin (NM-NM, NM-M, M-M)	Ordinal
Crowding index (number of family members per bedroom)	Continuous
Access to potable water (yes, no)	Dichotomous
Toilet access (yes, no)	Dichotomous
Mother's education [Level 1 (None or basic), Level 2 (Middle), Level 3 (Higher)]	Ordinal
School type (public or private)	Dichotomous
Head of household employment status (employer, employee, and self-employed)	Nominal
Family income[a]	Continuous

[a]Sum of the monthly monetary contribution made by all those helping to cover household expenses, in United States of America dollars.
NM: no Maya surname; M: Maya surname.

Sample selection

Participating individuals were measured at public and private schools in the north, center-west, east, and south of Merida. Schools were chosen by intentional sampling and individuals within each school were randomly selected. Participation was contingent on participant consent, permission to carry out measurements was given by each school and the experimental design was approved by the Bioethics Committee of the Center for Research and Advanced Studies (Centro de Investigación y de Estudios Avanzados - Cinvestav). Individuals were excluded if they exhibited sickness of any kind, stated that they received pharmacological treatment that might affect physical growth, or their records contained incomplete anthropometric and/or socioeconomic data. Final sample size was 844 for life conditions variables and 841 for growth parameters.

Techniques

Overall stature and KH were measured between 07:00 and 10:30 h. Participants were asked to wear their school sports uniform or were provided appropriate clothing by work group members. All anthropometric measurements were taken (after standardization) by trained personnel under supervision, following the protocol of Lohman et al. (1988). With the subject seated and the knees bent at a 90° angle, KH was measured with a device designed and built *ad hoc* following recommendations from Frisancho (pers. comm., 2010). The fixed portion of the device was placed next to the left foot and the movable portion placed at the upper surface of the thigh above the femoral condyles.

Participant's mothers were asked a series of questions on socioeconomic and biological aspects of their children and families (Table 1).

In a recent study of gene identity in 28 aboriginal American populations, the Mexican Maya were found to have an average gene identity of 0.325, in a range of 0.305–

0.522, indicating they have about 84% aboriginal ancestry and 14.6% European ancestry (Hunley and Healy, 2011). In the resulting rooted neighbor joining tree, the Mexican Maya were grouped with the Kaqchikel Maya from Guatemala in a cluster separated from three samples from Oaxaca (Zapotec, Mixes and Mixtecs) and two samples from the Andes (Quechuas and Aymaras) (Hunley and Healy, 2011, Fig. 2). In a study of four Maya samples from Guatemala and Mexico, Ibarra-Rivera et al. (2008) concluded that "As a whole, the Maya emerge as a distinct group within Mesoamerica, indicating that they are more similar to each other than to other Mesoamerican groups." (p. 329). This separation is supported by data on the AB0 and D genetic systems in samples from Yucatec Maya individuals showing a high degree of genetic homogeneity for these traits (González-Martínez et al., 1993; Serrano Sánchez, 1997). Based on this genetic separation, the presence of Maya surnames was used to represent Maya ancestry. This method has been used previously to make gross differentiations between groups of people with different genetic backgrounds (Chakraborty et al., 1989; Relethford, 1995). In Mexico, people have two surnames, the first is a patronym and the second a matronym. Maya surnames remain in wide use in Yucatan and can be readily distinguished from non-Maya surnames. Using the presence or absence of Maya paternal and maternal surnames, three categories were generated: (1) no Maya surnames, No Maya-No Maya (NM-NM); (2) one Maya surname, Maya-No Maya (M-NM); and (3) two Maya surnames, Maya-Maya (M-M). Surnames were initially identified by two members of the research team (AVV and FD) and confirmed using a specialized dictionary (Barrera Vázquez, 2001). Finally, an expert in the Maya language verified the 171 Maya surnames on the resulting list.

The crowding index was determined by the ratio of the number of family members to the number of rooms used for sleeping; ratios ≥ 3 were considered crowding (UN-HABITAT, 2006). When both parents had income, head of household employment status was determined for the parent (father or mother) who reported the highest income, assuming this person covered most household expenses. Three categories were used to classify employment status: employer, employee, and self-employed. Family income was the sum of the monthly monetary contribution made by all those helping to cover household expenses. Mother's, rather than father's, education level was used because child growth measurements and health condition are reported to increase as MEL increases (Alarcón et al., 2008; Chrzastek-Sprunch et al., 1984; Moguel, 2011). Education levels were (1) None or basic: no formal education, elementary or junior high complete or incomplete; (2) Middle: high school or short vocational degrees complete or incomplete; (3) High: bachelors, masters, doctorate, and technical degrees complete or incomplete.

Statistical analysis

Descriptive statistics were generated by ancestry for the variables used. Most analyses focused on identifying differences between the M-M, M-NM and NM-NM groups for the studied variables (Table 1). Considering ancestry in all cases, a Kruskal-Wallis non-parametric test was applied to the family income and birth weight variables. To test association between variables, a Chi^2 was applied to the employment status, school type, crowding index, piped water and toilet access, and MEL variables. A Spearman test was applied to measure the correlation between MEL and ancestry. A Mann-Whitney test was then used to identify significant differences in birth weight between boys and girls, without considering ancestry.

Multiple regression models were generated to identify the biological, environmental, social, and economic variables that best explained the variation in stature, KH and the KHSI as growth measurements. To determine which variables were most related to each growth measurement, paired correlation coefficients were run for the continuous variables, and a Spearman correlation test was applied for ordinal variables. Explanatory models were then built for stature and KH behavior using age and sex to control for their effects, with ancestry as the central element. Other variables included to explain growth measurement behavior included birth weight, age, crowding index, and family income. The models were validated by confirming that they met residual assumptions such as normality, variance homogeneity, and independence. Non-collinearity between explicative variables was corroborated by calculating the inflation factors for variance between them. Because stature and KH are important direct measurements of growth and body proportionality, the model coefficients were standardized to identify the variables which most affected them.

Significance level was 0.05 in all tests. All statistical analyses were run with the Stata/IC 11.1 for Windows statistics package (StataCorp LP, 2010).

RESULTS

Between September 2008 and December 2009, a total of 844 subjects were measured, 52.84% (446) women and 47.16% (398) men; 106 subjects had two Maya surnames (Table 2).

TABLE 2. Distribution of the sample by sex and ancestry

Ancestry	Girls (%)	Boys (%)	Total (%)
M-M	59 (13.2)	47 (11.8)	106 (12.0)
M-NM	116 (26.0)	93 (23.4)	209 (25.0)
NM-NM	271 (60.8)	258 (64.8)	529 (63.0)
Total (%)	[a]446 (52.8)	[a]398(47.2)	844 (100.0)

[a]Percentage over the total sample.
% = percentage.
M-M: Maya-Maya; M-NM: Maya-no Maya; NM-NM: no Maya-no Maya.

Social and economic conditions

Significant differences were present in the family income medians by ancestry: $306.7 for MM; $322.0 for M-NM; and $1227.0 United States dollars for NM-NM (Kruskal-Wallis non-parametric test; $X^2_2 = 236.6$, $P < 0.001$) (See exchange rate as of 31 December 2009 SAT, 2012). Analysis of the averages and means for family income showed that the NM-NM group was the source of the difference (Table 3).

Sample distribution by ancestry and employment status indicated most of the studied individuals belonged to families of employees (Table 3), with differences ($X^2_{(4)} = 34.30$, $P < 0.001$) by ancestry; the NM-NM group was associated with a higher frequency of employers.

In terms of MEL, mothers of M-M children most frequently had a Level 1 education (92.4%), followed by

TABLE 3. Living conditions of children and adolescent, by ancestry

Variable	M-M	M-NM	NM-NM	Statistical tests
Total family income[a,b]	$306.7	$322.0	$1,227.0	$X^2_{(2)} = 236.6, P < 0.001$
Employment level (%)				
Employees	73.6	75.6	69.6	$X^2_{(4)} = 34.30, P < 0.001$, Cramer's V = 0.143
Self-employed	21.7	19.1	12.3	
Employer	4.7	5.3	18.2	
MEL (%)				
1 None or basic	92.4	74.5	25.2	$X^2_{(4)} = 266.1, P < 0.001$, Cramer's V = 0.398
2 Middle	5.7	16.8	24.4	
3 Higher	1.9	8.7	50.4	
Type of School (%)				
Public	100.0	91.9	38.9	$X^2_{(2)} = 256.22, P < 0.001$, Cramer's V = 0.551
Private	0	8.1	61.1	
Crowding index (%)				
With overcrowding	67.9	53.6	22.7	$X^2_{(2)} = 115.63, P < 0.001$, Cramer's V = 0.370
Without overcrowding	32.1	46.4	77.3	
Access to potable water (%)				
With access	80.2	74.2	90.0	$X^2_{(2)} = 31.17, P < 0.001$, Cramer's V = 0.192
Without access	19.8	25.8	10.0	
Toilet access (%)				
With access	84.0	85.7	96.0	$X^2_{(2)} = 32.23, P < 0.001$, Cramer's V = 0.195
Without access	16.0	14.3	4.0	

[a]Median.
[b]Sum of the monthly monetary contribution made by all those helping to cover household expenses, in United States of America dollars.
M-M: Maya-Maya; M-NM: Maya-no Maya; NM-NM: no Maya-no Maya.

TABLE 4. Descriptive statistics for birth weight (kg), by sex and ancestry

	M-M		M-NM		NM-NM		Total	
	G	B	G	B	G	B	G	B
n	53	40	100	83	249	252	402	375
Mean	3.08	3.12	3.07	3.36	3.12	3.32	3.11	3.31
SD	0.49	0.48	0.60	0.58	0.51	0.50	0.53	0.52
Median	3.05	3.08	3.00	3.30	3.10	3.31	3.10	3.30
IQR	0.75	0.70	0.80	0.65	0.65	0.70	0.70	0.65

M-M: Maya-Maya; M-NM: Maya-no Maya; NM-NM: no Maya-no Maya; G: girls; B: boys; *n*: number of subjects; SD: standard deviation; IQR= interquartil range.

mothers of M-NM children (74.5%), and of NM-NM children (25.2%) (Table 3). A Spearman correlation test revealed a significant relationship ($S_r = 0.536$, $P < 0.001$) between MEL and child's ancestry considered as ordinal variables.

School type generally reflected a participant's social and economic status. This is differed by ancestry in that all M-M individuals attended public schools. Ancestry was related to the percentages of families experiencing crowding (Table 3) in that M-M families were more frequently crowded. This was also the case for piped water access and toilet access (Table 3).

In summary, the M-M families had the lowest family income of the three groups (just 25% of NM-NM family income), were largely employees and had a MEL 1. All the M-M subjects in the sample attended public schools and experienced a higher frequency of crowding at home and less access to piped water and toilets.

Biological variables

On average, the sampled population had adequate birth weight (girls: 3.11 ± 0.53; boys: 3.31 ± 0.52). Girls had significantly lower birth weight than boys (Mann-Whitney; $z = -5.23$ $P < 0.001$). When considering ancestry, birth weight differed among boys (Kruskal-Wallis; $X^2_2 = 6.216$, $P = 0.045$) but not girls (Table 4).

In terms of linear growth, M-M girls and boys had lower stature than the other ancestry categories (Table 5). Both M-M girls and boys had overall lower KH (Table 5). In girls, this segment was longer in the M-NM group at 11–12 years of age, although M-M girls had greater KH than the M-NM girls at 16 years of age. At 10 and 17 years of age, the M-M and M-NM boys had very similar KH, while at 14 years of age the M-NM boys were similar to the NM-NM boys.

At 9 and 12 years, the M-NM and NM-NM boys had very similar KHSI values (Table 5), as did M-M and M-NM boys at 10, 11, 14, 15, and 17 years of age. In girls, the highest KHSI values were observed in the M-NM group at 10 and 13 years of age, and in the M-M group beginning at 15 years of age.

Growth measurement statistical models

The stature multiple regression model showed that the variables included in the model explain 69% of variance in height (Table 6).

Age and sex were positively linked to stature, as expected. In other words, height was higher with greater age, and was 4.23 cm greater ($P \leq 0.001$) in boys than in girls. Birth weight and MEL best explained variance in height. Crowding was negatively linked to height since girls or boys living in a crowded family exhibited 0.63 cm less height per additional person per room. Ancestry negatively affected stature. Compared to the NM-NM subjects, the M-NM subjects were 1.62 cm ($P = 0.028$) shorter, and the M-M subjects 2.15 cm ($P = 0.024$) shorter.

For KH, the variables used explained 59% of variance (Table 7). Boys had a significantly longer KH, while birth weight, age, and MEL positively influenced KH. Crowding had a negative effect ($P = 0.027$): the more people per room the shorter the KH. Number of Maya surnames had a negative but not significant effect on KH. Children in the M-M group had shorter KH (Table 7).

The KHSI multiple regression model (Table 8) indicated that the variables explained 15% of variance. Again, sex, age, birth weight, and MEL had significant effects. KHSI

TABLE 5. Descriptive statistics of height (cm), KH (cm), and KHSI, by sex and ancestry

		Girls							Boys							
Age (years)	**Ancestry**		**Height**		**Knee height**		**KHSI**			**Height**		**Knee height**		**KHSI**	
		n	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**n**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
9	M-M	0	——	——	——	——	——	——	2	130.35	3.75	40.55	0.07	31.12	0.95
	M-NM	14	135.49	8.18	42.59	2.59	31.44	0.59	10	133.82	6.30	41.99	2.43	31.37	0.71
	NM-NM	34	134.38	7.31	41.92	2.73	31.18	0.83	30	135.06	6.54	42.34	2.66	31.33	0.68
	TOTAL	**48**	**134.70**	**7.50**	**42.11**	**2.68**	**31.26**	**0.77**	**42**	**134.54**	**6.36**	**42.17**	**2.54**	**31.33**	**0.68**
10	M-M	13	135.94	7.12	42.72	2.42	31.42	0.44	7	132.39	3.63	42.23	1.96	31.89	0.84
	M-NM	17	138.84	5.83	43.98	1.99	31.68	0.59	16	133.59	5.68	42.62	2.02	31.90	0.55
	NM-NM	26	139.52	7.61	43.76	2.69	31.36	0.64	33	138.69	6.81	43.76	2.61	31.54	0.67
	TOTAL	**56**	**138.48**	**7.02**	**43.58**	**2.44**	**31.47**	**0.59**	**56**	**136.45**	**6.68**	**43.24**	**2.43**	**31.69**	**0.67**
11	M-M	8	138.80	3.61	43.45	1.57	31.30	0.62	12	137.83	4.56	44.36	2.06	32.17	0.65
	M-NM	16	143.17	6.44	45.52	2.26	31.79	0.41	8	140.01	7.44	45.11	3.54	32.19	1.12
	NM-NM	32	143.05	8.10	44.87	2.70	31.37	0.57	28	143.69	6.39	45.80	2.71	31.86	0.70
	TOTAL	**56**	**142.48**	**7.23**	**44.85**	**2.50**	**31.48**	**0.57**	**48**	**141.61**	**6.57**	**45.32**	**2.73**	**31.99**	**0.77**
12	M-M	12	145.78	5.37	45.93	2.42	31.49	0.74	11	143.74	9.04	45.67	3.48	31.76	0.65
	M-NM	17	148.10	4.91	46.74	1.39	31.57	0.63	14	145.53	8.50	46.68	2.91	32.07	0.59
	NM-NM	37	149.61	5.90	46.63	1.96	31.17	0.65	30	152.51	9.31	49.14	3.77	32.20	0.82
	TOTAL	**66**	**148.52**	**5.67**	**46.53**	**1.92**	**31.33**	**0.68**	**55**	**148.98**	**9.73**	**47.82**	**3.76**	**32.08**	**0.74**
13	M-M	5	146.34	6.62	45.36	2.29	30.99	0.55	5	145.74	7.17	46.96	1.88	32.23	0.37
	M-NM	19	147.94	8.00	46.77	3.32	31.60	0.94	11	153.39	5.43	49.01	1.75	31.96	0.69
	NM-NM	28	153.47	7.36	48.13	3.00	31.35	0.91	14	160.93	7.66	51.66	2.29	32.11	0.53
	TOTAL	**52**	**150.76**	**7.98**	**47.37**	**3.15**	**31.41**	**0.90**	**30**	**155.63**	**8.71**	**49.90**	**2.67**	**32.07**	**0.56**
14	M-M	5	151.16	5.44	47.44	2.08	31.38	0.47	4	154.15	8.26	49.70	2.64	32.24	0.12
	M-NM	5	152.22	6.01	47.76	2.21	31.38	0.70	5	162.42	5.91	52.16	2.33	32.11	0.58
	NM-NM	24	155.80	6.74	48.62	2.90	31.19	0.86	25	163.24	8.81	52.07	3.30	31.89	0.94
	TOTAL	**34**	**154.59**	**6.58**	**48.32**	**2.69**	**31.25**	**0.78**	**34**	**162.05**	**8.69**	**51.80**	**3.13**	**31.97**	**0.84**
15	M-M	6	150.85	5.48	47.42	2.45	31.42	0.67	3	155.87	7.16	49.77	1.31	31.95	0.79
	M-NM	9	152.39	2.70	47.43	1.66	31.12	0.77	11	163.00	5.83	52.03	2.67	31.91	0.80
	NM-NM	31	155.01	4.86	48.27	2.02	31.14	0.71	27	168.84	7.07	53.31	2.59	31.57	0.59
	TOTAL	**46**	**153.96**	**4.79**	**48.00**	**2.01**	**31.17**	**0.71**	**41**	**166.32**	**7.69**	**52.71**	**2.69**	**31.69**	**0.66**
16	M-M	4	152.53	4.44	48.05	2.57	31.49	0.83	0	——	——	——	——	——	——
	M-NM	10	149.97	5.64	46.38	2.38	30.92	0.63	12	166.49	5.77	52.03	2.67	31.84	0.44
	NM-NM	36	155.02	6.31	48.63	1.89	31.04	0.58	39	170.50	7.23	53.58	2.81	31.42	0.81
	TOTAL	**50**	**155.08**	**6.27**	**48.13**	**2.22**	**31.05**	**0.61**	**51**	**169.56**	**7.07**	**53.44**	**2.59**	**31.52**	**0.75**
17	M-M	6	150.53	8.53	47.03	3.24	31.23	0.55	2	163.60	6.65	51.60	3.25	31.53	0.71
	M-NM	8	151.20	3.28	46.35	1.66	30.65	0.86	6	163.82	4.12	51.65	2.33	31.52	0.69
	NM-NM	22	156.57	6.59	48.16	2.19	30.74	0.68	32	171.38	7.72	53.80	2.83	31.39	0.71
	TOTAL	**36**	**154.37**	**6.81**	**47.56**	**2.66**	**30.80**	**0.71**	**40**	**169.85**	**7.76**	**53.37**	**2.84**	**31.42**	**0.69**

KHSI: knee height/stature index; n: number of subjects; SD: standard deviation; M-M: Maya-Maya; M-NM: Maya-no Maya; NM-NM: no Maya-no Maya.

TABLE 6. Multiple regression model for height (cm)

Variable	Coefficient	S. E.	*t*	*P*	CI 95%		S. C.
Age	3.83	0.11	35.72	0.000	3.62	4.04	0.74
Sex (Boys)	4.23	0.55	7.73	0.000	3.15	5.30	0.32
MEL 3 (higher)	4.08	0.80	5.12	0.000	2.51	5.64	0.31
MEL 2 (middle)	3.15	0.80	3.94	0.000	1.58	4.71	0.24
Birth weight	2.78	0.51	5.45	0.000	1.78	3.79	0.11
Crowding index	−0.63	0.27	−2.32	0.021	−1.17	−0.10	−0.06
One Maya surname	−1.62	0.73	−2.21	0.028	−3.10	−0.18	−0.12
Two Maya surnames	−2.15	0.95	−2.27	0.024	−4.01	−0.30	−0.16
Constant	88.37	2.43	36.39	0.000	83.60	93.14	−0.26

$n = 769$, F $(8,760) = 211.65$, $P = <0.001$, adjusted $R^2 = 0.69$, root mean square error = 7.42; Testing residual normality: Shapiro-Wilk: $w = 0.99$, $P = 0.268$ and Shapiro-France: $w' = 0.99$, $P = 0.377$; Breusch-Pagan/Cook-Weisberg homocedasticity test: $X^2_{(1)} = 1.59$, $P = 0.208$; There was no collinearity of the variables of the model according to the Inflation Factor Variance (IFV).
S.E.: standard error; S. C.: standardized coefficients.

increased 0.22% per additional kilogram at birth, indicating a longer lower leg. A MEL 3 represented a 0.27% decrease in the index value, again representing a relatively shorter lower leg. Number of Maya surnames had no significant effect on KHSI values.

DISCUSSION

That growth of Yucatec groups and, in particular, Maya children and adolescents is affected by social and economic conditions has been reported previously (Siniarska and Wolanski, 1999a; Wolanski et al., 1993), supporting the present results indicating that M-M groups largely belong to lower social and economic levels. In the studied sample, families with at least one Maya surname were at a lower socioeconomic level than those with no Maya surnames (Table 3).

Birth weight is known to be associated with an individual's growth and nutritional status (Herngreen et al., 1994; Ulijaszek et al., 1998; Varela Silva et al., 2009). For example, in a study of Yucatec Maya children from 4 to 6 years of age, a birth weight <3 kg was associated with a three fold increase in the probability of growth retardation (Varela Silva et al., 2009). The present data do not directly support Varela et al. (2009), but birth weight was found to positively affect stature ($P \leq 0.001$), which increased by 2.78 cm per additional kilogram at birth. A larger percentage of girls (8.7%) had low birth weight (i.e., <2.5 kg) than boys (5.4%).

Observed differences in stature between the three ancestry groups (M-M, M-NM, and NM-NM) were similar

TABLE 7. Multiple regression model for KH (cm)

Variable	Coefficient	S. E.	*t*	*P*	CI 95%		S. C.
Age	1.14	0.04	27.88	0.000	1.06	1.22	0.66
Sex (Boys)	2.03	0.21	9.73	0.000	1.62	2.44	0.46
MEL 3 (higher)	0.83	0.30	2.73	0.006	0.23	1.42	0.19
MEL 2 (middle)	0.80	0.30	2.62	0.009	0.20	1.40	0.18
Birth weight	1.21	0.19	6.20	0.000	0.82	1.59	0.15
Crowding index	−0.23	0.10	−2.21	0.027	−0.43	−0.02	−0.06
One Maya surname	−0.45	0.28	−1.62	0.106	−1.00	0.09	−0.10
Two Maya surnames	−0.57	0.36	−1.58	0.115	−1.28	0.14	−0.13
Constant	27.54	0.93	29.70	0.000	25.72	29.40	−0.28

$n = 769$, F (8,760) = 140.65, $P = <0.001$, adjusted $R^2 = 0.59$, root mean square error = 2.83; Testing residual normality: Shapiro-Wilk: $w = 0.99$, $P = 0.209$ and Shapiro-Francia: $w' = 0.99$, $P = 0.362$; Breusch-Pagan/Cook-Weisberg homocedasticity test: $X^2_{(1)} = 2.08$, $P = 0.149$; There was no collinearity of the variables of the model according to the Inflation Factor Variance (IFV).
S.E.: standard error; S. C.: standardized coefficients.

TABLE 8. Multiple regression model for KHSI (%)

Variable	Coefficient	S. E.	*t*	*P*	CI 95%		S. C.
Sex (Boys)	0.46	0.05	8.71	0.000	0.35	0.56	0.59
Birth weight	0.22	0.05	4.43	0.000	0.12	0.31	0.15
Two Maya surnames	0.07	0.09	0.78	0.433	−0.10	0.25	0.09
One Maya surname	0.04	0.07	0.60	0.549	−0.09	0.18	0.05
Age	−0.04	0.01	−3.89	0.000	−0.05	−0.02	−0.13
MEL 2 (middle)	−0.12	0.07	−1.61	0.107	−0.27	0.03	−0.15
MEL 3 (higher)	−0.27	0.07	−3.95	0.000	−0.41	−0.14	−0.35
Constant	31.20	0.21	149.13	0.000	30.79	31.61	−0.15

$n = 769$, F (7,761) = 20.89, $P = <0.001$, adjusted $R^2 = 0.15$, root mean square error = 0.72; Testing residual normality: Shapiro-Wilk: $w = 0.99$, $P = 0.432$ and Shapiro-Francia: $w' = 0.99$, $P = 0.477$; Breusch-Pagan/Cook-Weisberg homocedasticity test: $X^2_{(1)} = 0.12$, $P = 0.734$; There was no collinearity of the variables of the model according to the Inflation Factor Variance (IFV).
S.E.: standard error; S. C.: standardized coefficients.

to previous reports (Siniarska and Wolanski, 1999a; Wolanski et al., 1993), with relatively low height for M-M of both sexes. Among 17-year-old girls, M-M were 0.67 cm shorter than M-NM, but 6.04 cm shorter than NM-NM. In boys of the same age, M-M were 0.22 cm shorter than M-NM, but 7.78 cm shorter than NM-NM. For girls, the difference between M-M and NM-NM at this age was less than previous reports (Wolanski et al., 1993), while between groups of boys the differences were greater than reported elsewhere (Siniarska and Wolanski, 1999a).

Within the M-M group, average stature at 17 years of age (girls = 150.53 cm, boys = 163.6 cm), was greater than the 145 and 153.97 cm reported by Steggerda (1941, 1977) for girls and boys living in Maya villages.

MEL and child birth weight were more significant than ancestry in explaining stature data behavior. These results agree with Chrzastek-Sprunch et al. (1984) and Moguel (2011), who state that a MEL higher than junior high positively affects child growth, and Herngreen et al. (1994) and Ulijaszek et al. (1998), who report that birth weight is positively associated with final adult height.

In sum, the present results contradict claims that short stature among the Maya has its sole source in genetic differences (Diamond, 1992; Steggerda, 1941, 1977). Indeed, the socioeconomic conditions of M-M families (Table 3) had a much greater effect than ancestry on growth in children and young people. This is supported by two previous studies showing how drastic improvements in living conditions can cause favorable biological responses such as greater stature. In a study of children from 4 to 14 years of age born to immigrant Maya Guatemalan parents in Los Angeles, California, and in Florida, Bogin, and Loucky (1997) reported an increase in height of 5.5 cm compared to Maya children of the same age range in Guatemala. They did not measure the effect of socioeconomic variables that could have explained this notable improvement in physical growth, although their analysis did show that families that invested more social and economic resources in their children had taller children. In another study of Maya children from 5 to 12 years of age living in the United States or Guatemala, Bogin et al. (2002) reported that those living in the US were 11.54 cm taller than those in Guatemala at the same age. This is clearly inconsistent with any sort of genetic predisposition among the Maya for short stature.

Intergroup differences in KH (Table 5) indicate this parameter was generally similar between boys and girls, regardless of ancestry group. Clear differences by sex were observed since from 9 to 17 years of age KH increased by 5.45 cm in girls but by 11.2 cm in boys.

Birth weight and MEL made significant contributions to explaining KH behavior, far greater than the presence of one or two Maya surnames. Apparently, this parameter responds mostly to changes in the developmental environment, *in* or *ex utero*, rather than to ancestry.

The overall study hypothesis was not supported by the data since KHSI values varied minimally (indicated by small standard deviations), and regardless of ancestry; that is, KHSI values in the studied sample did not significantly decrease as the number of Maya surnames increased. In contrast, mother's education (particularly Level 3), and child birth weight explained a large portion of KHSI behavior (Table 8), suggesting that these two variables contributed to creating an adverse growth environment for the M-M and, in less extent, for the M-NM groups of the studied sample.

The holistic human ecology perspective applied here to the question of variation in stature contributed significantly to better understanding the causes of short stature among the Yucatec Maya. The specific variables used are all known to influence growth and body proportionality in children and young people. Previous studies identified lower limb proportions as a practical indicator of the effect of environmental quality and variations on growth (Bogin et al., 2002; Frisancho, 2007; Frisancho et al., 2001; Gigante et al., 2009; Gurri and Dickinson, 1990; Leitch, 1951; Malina et al., 2004; Padez et al., 2009; Sanna and Soro, 2000; Siniarska and Wolanski, 1999a). To the best of our knowledge, the present study is the first to address this issue in the population of Yucatan, particularly its Maya population.

CONCLUSIONS

1. Maya ancestry had a negative effect on stature and KH, but biological (e.g., birth weight), environmental (e.g., crowding), and socioeconomic variables (MEL) explained a greater portion of the differences in growth measurements than did ancestry.
2. Body proportion in the form of the KHSI was not affected by ancestry and was explained mostly by birth weight and MEL.

3. The data indicate that the studied growth and body proportion measurements respond to variations in the growth environment rather than to ancestry, a proxy for genetics.
4. Individuals in the sample who had developed in an adverse environment (i.e., MEL 1) had lower stature and KH but a relatively longer lower leg.
5. Given the difference in height between M-M and NM-NM in both boys and girls (Table 5), and the height regression model results (Table 6), the only possible explanation to such differences in total height is that femur and/or trunk length were longer in the NM-NM individuals; if so, such body segments are more sensitive to environmental variables than the tibia in the studied sample.
6. In this sample, belonging to a certain social and economic group had a greater effect on stature, KH and the KHSI than belonging to a given ancestry group.

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