ORIGINAL ARTICLES

Maternal Height and Child Growth Patterns

O. Yaw Addo, PhD[1], Aryeh D. Stein, PhD[1], Caroline H. Fall, DM[2], Denise P. Gigante, PhD[3], Aravinda M. Guntupalli, PhD[4], Bernardo L. Horta, PhD[3], Christopher W. Kuzawa, PhD[5], Nanette Lee, PhD[6], Shane A. Norris, PhD[7], Poornima Prabhakaran, MBBS[8], Linda M. Richter, PhD[7], Harshpal S. Sachdev, MD[9], and Reynaldo Martorell, PhD[1], on behalf of the Consortium on Health Orientated Research in Transitional Societies (COHORTS) Group*

Objective To examine associations between maternal height and child growth during 4 developmental periods: intrauterine, birth to age 2 years, age 2 years to mid-childhood (MC), and MC to adulthood.

Study design Pooled analysis of maternal height and offspring growth using 7630 mother–child pairs from 5 birth cohorts (Brazil, Guatemala, India, the Philippines, and South Africa). We used conditional height measures that control for collinearity in height across periods. We estimated associations between maternal height and offspring growth using multivariate regression models adjusted for household income, child sex, birth order, and study site.

Results Maternal height was associated with birth weight and with both height and conditional height at each age examined. The strongest associations with conditional heights were for adulthood and 2 years of age. A 1-cm increase in maternal height predicted a 0.024 (95% CI: 0.021-0.028) SD increase in offspring birth weight, a 0.037 (95% CI: 0.033-0.040) SD increase in conditional height at 2 years, a 0.025 (95% CI: 0.021-0.029 SD increase in conditional height in MC, and a 0.044 (95% CI: 0.040-0.048) SD increase in conditional height in adulthood. Short mothers (<150.1 cm) were more likely to have a child who was stunted at 2 years (prevalence ratio = 3.20 (95% CI: 2.80-3.60) and as an adult (prevalence ratio = 4.74, (95% CI: 4.13-5.44). There was no evidence of heterogeneity by site or sex.

Conclusion Maternal height influences offspring linear growth over the growing period. These influences likely include genetic and non-genetic factors, including nutrition-related intergenerational influences on growth that prevent the attainment of genetic height potential in low- and middle-income countries. *(J Pediatr 2013;163:549-54)*.

Adult height is the cumulative result of the interaction between environment and genetics over the growing period. In developing countries, growth failure in the first 1000 days (conception to 2 years) of life[1-3] is a strong determinant of final adult height.[2] Among adults, short adult is associated with reduced human capital.[4] Short maternal height is associated with low offspring birth size, childhood stunting, and reduced human capital,[5-8] likely in part due to maternal physical constraints on offspring growth in utero.[9] Shorter women may have reduced protein and energy stores, smaller reproductive organ sizes, and limited room for fetal development.[10,11] These influence fetal growth via the placenta and infant growth through breast milk quantity and quality.[12] Beyond this period, correlations between maternal and child heights are expected to be strongly influenced by genetics.[13]

Several studies have examined the cross-sectional association of maternal height with child size at birth and at selected postnatal ages,[6,14,15] but there is less known about the relationship between maternal height and offspring growth over the life course. In particular, we are not aware of any studies examining the relationship between maternal height and offspring postnatal linear growth during specific, potentially critical, developmental periods. Such evidence would help inform policies and programs to prevent growth failure and to assess its intergenerational consequences. Estimating the separate impacts of maternal height on specific periods of growth is fraught with methodological difficulties because growth in distinct intervals is correlated within a child. We address this challenge by using growth modeling techniques that partition correlated longitudinal data into distinct and orthogonal components. We then relate maternal height to growth during these distinct periods. The objective of this study is to examine associations between maternal height and child growth

COHORTS	Consortium on Health Orientated Research in Transitional Societies
HAZ	Height-for-age z-scores
LMICs	Low- and middle-income countries
MC	Mid-childhood
MI	Multiple imputations
PR	Prevalence ratio
SES	Socioeconomic status

From the [1]Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, GA; [2]Medical Research Council Lifecourse Epidemiology Unit, University of Southampton, Southampton, United Kingdom; [3]Postgraduate Program in Epidemiology, Universidade Federal de Pelotas, Pelotas, Brazil; [4]Center for Research on Ageing, University of Southampton, Southampton, United Kingdom; [5]Department of Anthropology, Northwestern University, Evanston, IL; [6]Office of Population Studies Foundation, University of San Carlos, Cebu, Philippines; [7]Medical Research Council/Wits Developmental Pathways for Health Research Unit, Faculty of Health Sciences, University of the Witwatersrand, South Africa and Human Sciences Research Council, Johannesburg, South Africa; and [8]Public Health Foundation of India; and [9]Department of Pediatrics, Sitaram Bhartia Institute of Science and Research, New Delhi, India

*List of members of the COHORTS Group is available at www.jpeds.com (**Appendix 1**).

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during 4 developmental periods: intrauterine, birth to age 2 years, age 2 years to mid-childhood (MC), and MC to adulthood.

Methods

We analyzed data from the 5 studies that participate in the Consortium on Health Orientated Research in Transitional Societies (COHORTS).[16] These include the 1982 Pelotas Birth Cohort–Brazil,[17] the Institute of Nutrition of Central America and Panama Nutrition Trial Cohort (INTCS)–Guatemala,[18] the New Delhi Birth Cohort–India,[19] the Cebu Longitudinal Health and Nutrition Survey (CLHNS)–Philippines,[20] and the Birth to Twenty (BT20) Cohort–South Africa[21] (Table I).

Maternal height and offspring anthropometric measurements were measured following site-specific protocols.[2] Maternal height was measured using a stadiometer to the nearest 0.1 cm following standard procedures. All observers were trained in anthropometric techniques by experts and subsequently assessed for the reliability of their measurements, which fell within technical errors of measurement.[22] Maternal height was measured at cohort enrollment/baseline in Brazil and the Philippines, and various time points around birth or in childhood for the other sites. Child data collected at birth, 2 years, a point we denote as MD, and adulthood were used in the present analysis. The MD point varied across sites because of variation in data collection schedules across the 5 cohorts. It was 48 months in Brazil, Guatemala, and India, 60 months in South Africa, and 102 months in the Philippines. We denote the interval between MC and adulthood as late childhood. Birth length was not available for Brazil and South Africa. Offspring birth weight was measured by the field research staff in Brazil, India, and Guatemala. In the Philippines, it was obtained from both field measurements and hospital records. In South Africa, it was obtained from birth records assessed for reliability.[23] Offspring attained height-for-age z-scores (HAZ) at age 2, at MC, and in adulthood were calculated using the 2006/7 World Health Organization standard reference curves.[24,25] To compute the adult HAZ we used the tabulated Lambda, Mu, Sigma (the child growth modeling method/parameters for the World Health Organization curves) values for age 19 years, under the assumption that adult height is substantively attained by this age.

Statistical Analyses

We included in the analysis all mother–child pairs with available anthropometry data in all periods (n = 7630). One or more predictors were missing for 19% of the analytic sample. We assumed the missing predictors (maternal height and household wealth) to be missing at random, and generated 5 multiple imputations (MI) using imputation chain equations. Combined estimates were obtained using MI inference rules.[26] Analyses conducted with the available non-missing data (by list-wise deletion) had similar results but with wider CIs and, consequently, we kept the results of the MI analyses.

Maternal height was the primary exposure. Child growth (birth weight, height changes during the early, middle, and late childhood periods) and attained height (all in z-scores) were the outcome measures.

To address the challenge of collinearity of growth measures, we computed conditional height, the child-specific residual obtained from linear site-specific regression of height at each age on birth weight and all prior height measurements.[27] Conditional height represents the change in height within a growth period relative to the child's prior height, in the context of the mean growth pattern of the population. Conditional variables are uncorrelated with each other. We used birth weight as the anchor for all conditional heights.

We defined offspring childhood stunting at 2 years as HAZ values <-2 SD.[24] Using the same threshold of -2 SD, short stature in adulthood was defined as height <150.1 cm among females and <161.9 cm among males.[25] We used study-specific measures of socioeconomic status (SES) at offspring birth, categorized into quintiles (1 = poorest) as a measure of SES during childhood. The SES quintiles are site-specific, and were estimated from maternal education and paternal occupation for India, and by asset scores for all other study sites.

Descriptive characteristics are presented as means (SD) for continuous variables or as percentages for categorical variables. We assessed the secular trends in adult heights across

Table I. Descriptive characteristics of the 5 cohorts

Cohort	Design	Enrollment year	Cohort description	Analytic sample*
Pelotas Birth Cohort, Brazil	Prospective cohort	1982	Children born in the city's maternity hospital (>99% of all births in 1982). All social classes included.	3535
INTCS, Guatemala	Community trial	1969-77	Intervention trial of a high-energy and protein supplement in women, and children <7 years in 1969 and born during 1969-1977 in 4 villages.	299
New Delhi Birth Cohort, India	Prospective cohort	1969-72	Babies born to an identified population of married women living in a defined area of Delhi. Primarily middle class sample.	836
CLHNS, Cebu, Philippines	Prospective cohort	1983-4	Pregnant women living in 33 randomly selected neighborhoods; 75% urban. All social classes included.	1892
BT20 Cohort, Johannesburg-Soweto, South Africa	Prospective cohort	1990	Babies born to pregnant women living in a defined urban geographical area in Johannesburg. Predominantly poor, Black sample.	375

INTCS, Institute of Nutrition of Central America and Panama Nutrition Trial Cohort; *CLHNS*, Cebu Longitudinal Health and Nutrition Survey; *BT20*, Birth to Twenty.
*Observations with data for maternal height and offspring birth weight, and height/length for data collections points of birth, 2 years, in MC, and in adulthood.