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Original Article

Growth Characteristics of Four Low- and Middle-Income Countries Children Born just After the Millennium Development Goals

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ABSTRACT

Introduction: Socioeconomic inequality among low- and middle-income countries has an immense impact on the growth characteristics of children. Consequently, the millennium development goals were established for action to fight poverty and reduce the health problems for most disadvantaged groups.
Objectives: The objectives of this study were to investigate the growth characteristics and correlates of height growth among children in low- and middle-income countries.
Methods: Data from the Young Lives study conducted in Ethiopia, India, Peru and Vietnam for 15 years were used. A linear mixed-effects fractional polynomial modeling approach was used to analyze the growth characteristics and to assess the determinants.
Results: There was a significant growth difference in height among children in low- and middle-income countries. Children in Vietnam grew at a faster rate during the entire period considered (1-15 years). In four countries, children grew very quickly in early childhood and the growth rates slow down gradually during the consecutive years. The results show that factors such as gender, parents' education, household size, wealth index, access to sanitation, fathers' age and residence area are significantly associated with child growth.
Conclusion: The functional relationship between height growth and time is nonlinear. Males are taller than females at an early childhood age. Children from the most educated father and mother had been taller than those from the least educated father and mother. The effect of the household wealth index is positive on height growth, while the effect of household size is negative.

Introduction

Children's physical growth often occurs in stages with distinctive characteristics. These stages are characterized by the rate of growth. The growth rate of children from infancy to adulthood follows irregular growth patterns (1,2). The physical growth of children has an association with the economic status of the country. The association between the

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socioeconomic structure of society and health is a linear gradient. Therefore, characteristics of growth vary among distinct socioeconomic statuses, families, and ethnic groups. Consequently, several children in low- and middle-income countries who live in poor communities have poor growth especially in their first two years of life (3,4). For instance, Zong X and Li H (2) reported that the mean height of adolescents have a strong correlation with China's gross domestic product per capita ($r = 0.90$) and variations in mean height were observed in areas having different economic statuses. A similar study conducted by Mumm and Aßmann (5) discussed the effect of a geographic cluster on the height growth of children in low-and middle-income countries and reported that the difference in height growth was significantly associated with a geographic cluster (i.e., rural and urban). Poor child growth is the consequence of a range of factors that are closely linked to the overall standard of living. Tracking children's health and development problems in developing countries is a critical challenge. However, Millennium Development Goals endorsed the goals to be achieved by 2015 to improve the living conditions of developing countries (6).

Three of the 8 living conditions Millennium Development Goals (MDGs) are directly health-related, such as reduce child mortality, maternal deaths, and combat malaria and HIV/AIDS and other diseases (6). Millennium development goals have direct and indirect effects on child development. Aside from genetics, nutrition and childhood disease are universally the most significant environmental factors affecting child height development (7). Physical height is a good pointer of living conditions in childhood. Short stature is linked to poorer education and lower social status (8). The household's income, hygiene and sanitation facilities influence the prevalence of stunting (9). The varieties of socioeconomic statuses found in low- and middle-income countries are ideal for researching height determinants. As a result, achieving MDGs has a significant role in improving child development.

The assessment of child growth does not only serves as a means for evaluating the growth trajectories but also provides the health and nutritional status of children in one country and evaluates the distribution in health facilities among the populations (10). Because of this, assessing the growth characteristics of children in low- and middle-income countries is very important in understanding the general patterns of growth among children, for monitoring the population's nutritional status and for distinguishing the causal effects of growth in the population. Moreover, it is important for developing effective interventions and policies in the countries. In addition, understanding the growth characteristics of children is important to forecast future trends of growth and help to compare the influence of several interventions (11). Therefore, this study aims to assess and compare the difference in height growth among children growing up with the promise of millennium development goals in Ethiopia, India, Peru and Vietnam. Besides, the study investigates the effects of selected covariates on child growth. The four countries represent a variety of socio-economic contexts in low- and middle-income countries.

Materials and Methods

Data from the Young Lives study were used. Young Lives is an international longitudinal research study designed for measuring childhood poverty and health in low- and middle-income countries. The study is being conducted in Ethiopia, India, Peru and Vietnam since 2002. The study followed children from infancy to middle-adolescence, ranged 1 to 15 ages, those growing up with the promise of the millennium development goals. Samples of 2000 children were selected from each country. Five rounds of quantitative and qualitative surveys of child's characteristics, household characteristics and environmental characteristics were collected every three/four years over a time of 15 years in longitudinal forms. The first survey round was conducted in 2002 when children were on average one year, the second was in 2006, the third was in 2009, the fourth was in 2013 and the fifth was carried out in 2016 (12).

Fractional Polynomial and Linear Mixed-effects Models

In longitudinal data, observations are measured repeatedly on the same outcome through time. These observations tend to be inter-correlated and this correlation must be taken into account in the analysis. A common goal of a longitudinal study is to assess the change of outcome over time using mixed-effects model (13,14). In modeling the outcome change over time, time (child's age) is considered as a covariate. Therefore, to assess the change of growth over time, the first step is to model the functional relationship between the outcome variable (height growth) and the time (15,16). The loess smooth curve provides a visual investigation of the average patterns of change over time (17). When the pattern of a smooth curve is nonlinear, the smoothed function is usually selected from several alternatives, such as conventional polynomials of various orders. Conventional polynomial models are a classical choice for modeling change of response over time in which it consists of power transformations of the time metric with the integer exponents. However, the curve does not often fit well the data both at lower and higher orders (18). There are alternative methods that can have some advantages over conventional polynomials in modeling nonlinear height growth. To tackle the difficulties of conventional polynomials, a class of time transformation known as a fractional polynomial model proposed by Royston and Altman (19) provides a wide range of functional forms in modeling such relationships. Fractional polynomial offers a useful extension to conventional polynomials as a way of smoothing and interpolating data and for exploring the character of possible nonlinear effects of continuous covariates. It provides a flexible parametric method, a wide variety of curve shapes at lower-degree and the ability to approximate asymptotes.

For continuous covariates, fractional polynomial techniques check whether the nonlinear function of the class of power terms improves the fit significantly (20,21). Lower-degree fractional polynomials offer a wide variety of curve shapes that apply to many applied situations and higher-degree functions are rarely needed (15,18,21,22). For simplicity, we used a second-order fractional polynomial which has the following forms,

$$\phi(t;\boldsymbol{\beta},\boldsymbol{p}) = \begin{cases} \beta_0 + \beta_1 t^p + \beta_2 t^q + \varepsilon, & for\ p \neq q \\ \beta_0 + \beta_1 t^p + \beta_2 t^q \ln(t) + \varepsilon, & for\ p = q \end{cases} \quad 1$$

where p and q are real-valued power terms selected from the predefined sets of $(-2, -1, -0.5, 0, 0.5, 1, 2, 3)$, β_0, β_1, and β_2 are intercept, coefficient of t^p and coefficient of t^q, respectively and ε is the error terms. Such a fractional polynomial model accommodates many linear and nonlinear curves as a special case (15,18,19). For instance, linear, quadratic, cubic, square root, reciprocal, logarithmic and their combinations. Among all the possible combinations of p and q, the best-fitting model is evaluated based on their deviance as well as AIC, BIC information criteria, where smaller is better (19).

A fractional polynomial model in equation (1) can be expressed in the context of linear mixed-effects models (23,24) as:

$$y = \boldsymbol{X}\beta + \phi(t;\beta,p) + Zb + \varepsilon \quad 2$$

The term $\boldsymbol{X}\beta$ is the fixed effects of covariates included in the model such as countries, child's gender, child's area of residence, fathers' level of education, mothers' level of education, fathers' age, mothers' age, number of household size, wealth, access to safe drinking water, access to sanitation, and the interaction between country and fractional polynomial function of time(child's age). By using the design matrix in equation (2), the significant effects of the main and interaction effects of the covariates can be modeled and evaluated at alpha 5 percent level of significance.

Results

Exploratory data analysis

Individual and group profile plots for the height growth of children in the four low- and middle-income countries are displayed in Figures 1 and 2, respectively. Across the countries, the plots of individual and mean

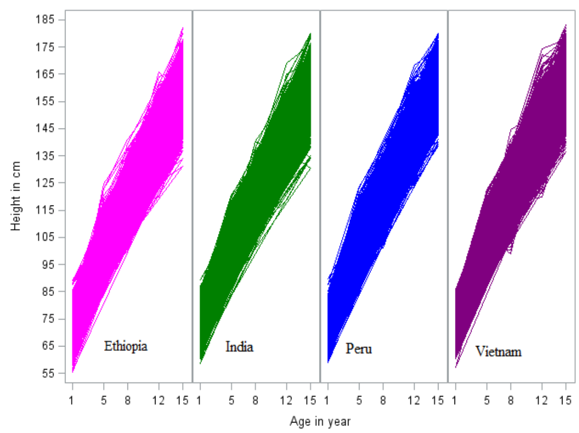

Figure 1. Individual profile plots for the height growth of children by country

changes do not show high variability in height growth, but a greater association between height growth and age was observed. As it can be seen from Figure 2, a sharp increment in the mean change was observed in early childhood and the increment becomes slow in all countries. This suggests that the functional relationship between height growth and time is nonlinear.

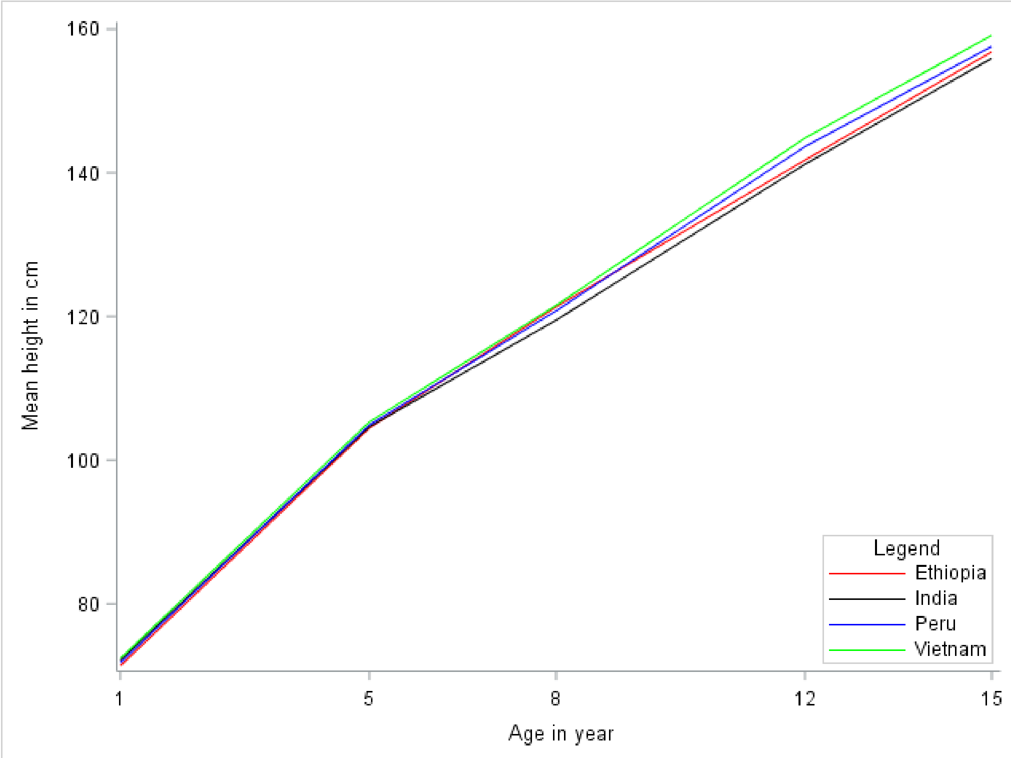

Figure 2. Group profile plots for height growth of children in low-and middle-income countries

Results of fitting linear mixed-effects fractional polynomial model

Height growth is analyzed as a function of time (child's age). The time variable was entered to model with single and combinations of power terms of p = -2, -1, -0.5, 0, 0.5, 1, 2 and 3, and q = -2, -1, -0.5, 0, 0.5, 1, 2 and 3. After comparing the deviance of all models, a model with p = -1 and q = 1 revealed the lowest deviance. Hence for the current height data, the best-fitting fractional polynomial function is found to be p = -1 and q = 1 power terms. This is the age effect function on the growth of the individuals. We then incorporated the fixed and random effects into the age effect model. Then, equation (2) can be rewritten as;

$\beta_0 + b_{0i} + (\beta_1 + b_{1i})t^{-1} + (\beta_2 + b_{2i})t + \varepsilon.$

The population parameters β_0, β_1, and β_2 represent the intercept, coefficient of time inverse (t^{-1}) and linear time (t) effects, respectively and b_{0i}, b_{1i}, and b_{2i} are the random effects associated with the influence of individual children on their repeated height growth over time. It is more likely that individuals will have a negative or positive influence on their longitudinal growth data (25). The random effects in the model explain between-individual variation in height growth. Therefore, to account for the difference between individuals, the random effects should be included in the model. We then compared the performance of models having different random effects (intercept, time inverse and linear time) using the likelihood ratio test statistics. Lastly, the results of the likelihood ratio test statistics provided that a model with the intercept only is preferable. In order to choose the appropriate covariance structure for the error terms, we used the likelihood-based information criteria: AIC, AICC, BIC, and HQIC, the smallest is better. Accordingly, we found that the heterogeneous first-order autoregressive covariance structure is the most appropriate for the model.

Using a selected random effect and time effects (i.e., time inverse and linear time), the final linear mixed-effects fractional polynomial model with covariates effect included in the model. The results of fitting linear mixed-effects models are given in Table 1 with the covariate effects of child's gender, countries, child's area of residence, access to safe drinking water, access to sanitation, fathers' age, mothers' age, household size, household wealth index, father's level of education, mothers' level of education, inverse-time, linear time and the interaction effect of time functions with countries. The result of the intercept indicates that the estimated mean height of the reference group is 83.11cm at the beginning of the cohort. The negative gender effect implies that the mean height of females is 1.33 times lower than that of males at the beginning of the cohort. The estimated values, -0.33, -1.63 and -1.37, reported for country effects indicate that the mean difference in height growth between children in Ethiopia and the corresponding countries. These values show that compared to children in Ethiopia children in Peru and Vietnam have lower mean height, but the difference is not statistically significant for children in India at the intercept. The difference in height growth between children in rural and urban is significantly negative ($p<0.0001$), suggesting that the mean height of children in rural is 1.03 times lower than the mean height of children in urban at the beginning of the cohort.

The fathers' and mothers' level of education is significantly related to their child's growth. As it can be seen from Table 1, the positive mean differences in height growth between children from most educated parents (secondary school and above) and uneducated parents imply that children from

Table 1. Parameter estimates of covariates effect in linear mixed-effects model

Effect	Estimate	SE	t-value	p-value
Intercept	83.1140	0.3975	209.10	0.0001*
Child's gender (female)	-1.3285	0.1106	-12.01	0.0001*
Country (ref. = Ethiopia)				
India	-0.3307	0.2978	-1.11	0.2668
Peru	-1.6251	0.3121	-5.21	0.0001*
Vietnam	-1.3715	0.3101	-4.42	0.0001*
Area of residence (rural)	-1.0256	0.1236	-8.29	0.0001*
Access to safe drinking water (yes)	-0.0683	0.0825	-0.83	0.4078
Access to sanitation (yes)	0.1720	0.0760	-2.26	0.0236*
Child's father age	0.0299	0.0119	2.52	0.0118*
Child's mother age	-0.0014	0.0142	-0.10	0.9239
Household size	-0.1083	0.0173	-6.25	0.0001*
Wealth	2.3506	0.2726	8.62	0.0001*
Father's level of education (ref. = uneducated)				
Primary school	-0.1673	0.1161	-1.44	0.1496
Secondary school	0.5917	0.1564	3.78	0.0002*
Diploma and above	0.5675	0.2189	2.59	0.0095*
Adult and religious education	-0.1581	0.2209	-0.72	0.4742
Mother's level of education (ref. = uneducated)				
Primary school	0.0806	0.1146	0.70	0.4822
Secondary school	1.1073	0.1668	6.64	0.0001*
Diploma and above	2.0407	0.2481	8.23	0.0001*
Adult and religious education	0.0586	0.2370	0.25	0.8047
$(time)^{-1}$	-16.3169	0.2029	-80.41	0.0001*
$time$	4.9633	0.0213	233.62	0.0001*
time and country (ref. = Ethiopia)				
$(time)^{-1}$ × India	0.6160	0.2720	2.26	0.0235*
$(time)^{-1}$ × Peru	0.4707	0.2825	1.67	0.0956
$(time)^{-1}$ × Vietnam	1.4429	0.2701	5.34	0.0001*
$time$ × India	-0.1062	0.0255	-4.16	0.0001*
$time$ × Peru	0.0672	0.0259	2.59	0.0096*
$time$ × Vietnam	0.1863	0.0251	7.42	0.0001*

Note: SE represents the standard error of the estimate, * significant at 5%.

most educated parents have a higher mean height compared to those from uneducated parents. However, there is no significant mean difference in height growth between children from uneducated parents and children whose parents have adult and religious education. Moreover, the mean height related to father age is significantly positive, indicating that fathers' age has a significant positive effect on a child's growth. In contrast, mothers' age has no significant effect on a child's growth. The effect of the wealth index is positive on height growth, while the effect of household size is negative on height growth. The effects of access to safe drinking water and mothers' age are not significant.

The interaction effects between time (time-inverse and linear time) and country are given in Table 1. It represents the differences in the rate of change between the reference group (Ethiopia) and the corresponding countries. The fitted growth models for each country under identical fixed effect values can be summarized as follow,

$$Ethiopia: \quad \hat{y}_{ij} = constant\_ET - 16.3169(time)^{-1} + 4.9633time$$

$$India: \quad \hat{y}_{ij} = Constant\_IN - 15.7009(time)^{-1} + 4.8571time$$

$$Peru: \quad \hat{y}_{ij} = Constant\_PE - 15.8465(time)^{-1} + 5.0305time$$

$$Vietnam: \quad \hat{y}_{ij} = Constant\_VT - 14.8740(time)^{-1} + 5.1496time$$

The instantaneous rate of change for each country can be computed from their marginal equations and have the following forms.

$$Ethiopia: \frac{d\hat{y}_{ij}}{d(time)} = \frac{16.3169}{(time)^2} + 4.9633$$

$$India: \frac{d\hat{y}_{ij}}{d(time)} = \frac{16.9329}{(time)^2} + 4.8571$$

$$Peru: \frac{d\hat{y}_{ij}}{d(time)} = \frac{15.8465}{(time)^2} + 5.0305$$

$$Vietnam: \frac{d\hat{y}_{ij}}{d(time)} = \frac{17.7598}{(time)^2} + 5.1496$$

The plots of growth rates presented in Figure 3 show that in all countries children grow very quickly in early childhood, but the growth rates decreasing gradually during the consecutive years. Vietnamese children grow at a faster rate throughout the entire period considered. Starting from age five the rate of growth for children in India is lower than the others.

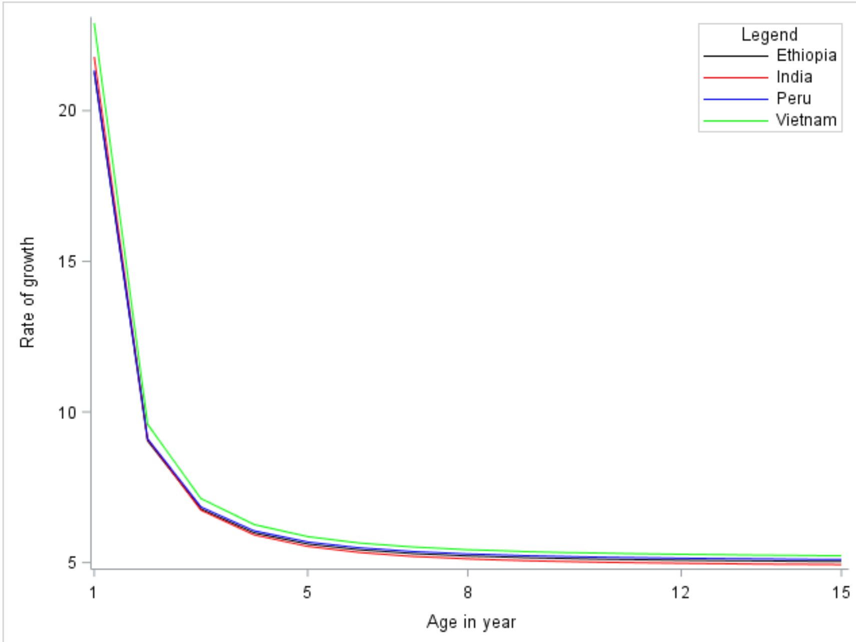

Figure 3. Plots of children's rate of growth in four low- and middle-income countries

Discussion

In this study, we investigated the general growth patterns and correlates of height growth among children in four low- and middle-income countries. The trends of loess smooth curves presented in Figure 2 shows a nonlinear relationship between the longitudinal height growth and time (age in years). Therefore, time transformation is needed to model height growth. Thus, the time transformation was identified using fractional polynomial approaches and the time-inverse and linear time were selected as the functions of height growth. To analyze the influence of different covariates on height growth, a linear mixed-effects fractional polynomial model was employed. The faster growth rate has occurred in early childhood. A higher rate of growth was observed in Vietnam during the entire cohort study. By contrast, it is low in Ethiopia at the earliest childhood and in India after early childhood. This may be due to weak governance systems and weak public health systems in Ethiopia and India. The lack of good governance biased the ability of health outcomes to be sustainable (26). Moreover, the variation in height growth among children in low- and middle-income countries could be due to the socioeconomic differences among these countries. This finding was previously suggested by Bann et al. (27) showed that shorter height has an association with socioeconomic position. The adolescents' average height has a close correlation with China's GDP per capita and differences in height were observed in areas having different economic characteristics (2).

Gender difference has a role in determining the variation in height growth. Males are taller than girls at the beginning of the cohort. A study in Japanese school-aged children showed that males and females have significant height gain differences from age

7.5 to 14.5 years (28). The growth rate of height is associated with the variation in the wealth of countries. Children from the most educated father and mother had been longer than those from the least educated father and mother. This finding is consistent with that of Patel et al. (29) in that parental education and height growth of children have a positive relationship.

Conclusion

The findings of this study help in understanding the growth characteristics and correlates of height growth among children in four low- and middle-income countries. A significant growth difference in height was detected among children in low- and middle-income countries. A higher rate of growth was observed in Vietnam during the entire childhood age. Children in Ethiopia showed a higher intercept and lower growth rate at the early childhood age.

Conflict of Interests

The authors have no conflicts of interest to disclose.

Acknowledgments

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