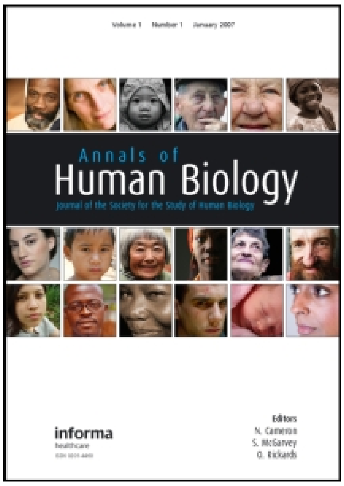

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Effects of heterosis on growth in height and its segments: a cross-sectional study of the Khasi girls in Northeast India

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Summary. *Background*: It is generally believed that improvement in environmental quality is the main factor responsible for the better growth and nutritional status of children in developing countries. However, it is still not clear whether this better growth performance is also associated with heterosis and/or gene flow that may take place as a result of the geographical movement of individuals, or migration.
Aim: The present paper attempts to examine the effects of heterosis on physical growth of girls in height and its segments.
Subjects and methods: A cross-sectional sample of the Khasi girls of Shillong in Northeast India was considered in the present analysis. The height and sitting height of 1368 girls aged 3–18 years were measured with a Harpenden anthropometer, following standard techniques. The sample was divided into two groups, namely hybrid (HB) and non-hybrid (NHB) girls, in order to test the effects of heterosis using analysis of covariance with the household income as a covariate. The Preece–Baines model 1 (M. A. Preece and M. F. Baines, *Annals of Human Biology*, **5,** 1–24, 1978) was used to fit the adjusted means of height and its segments with a view to assess the variation in adult height, age at peak velocity and size at peak velocity.
Results: Both HB and NHB girls were similar in age at maximum increment for height (12 years) and sitting height (13 years), although it was much earlier in the former (10.5 years) than in the latter (11.9 years) with respect to subischial length. The results indicated that HB girls were larger than NHB girls across ages. Such a higher anthropometric status in HB girls was mainly due to their higher growth velocities before the adolescent period. The effect of heterosis after household income was highly significant at many ages from 6 to 18 years, although it was not clearly perceptible in the case of subischial length.
Conclusion: Subject to further studies, the role of heterosis and/or gene flow in influencing growth and development of children cannot be completely ruled out, especially after 5 years of age when the variation in growth patterns is likely to be associated not only with environmental quality but also with genetic mechanisms.

1. Introduction

Physical growth variation between populations is generally attributed to both genetic and environmental factors. One of the main conclusions with regard to the variation in growth due to environment is the variation between socio-economic classes within a population, especially in developing countries like India. It is well documented that children belonging to the higher socio-economic strata of populations in developing countries are heavier and taller than their counterparts belonging to the lower socio-economic strata in the same age groups. Accordingly, it is generally assumed that the growth failure in developing countries is mainly due to inadequate nutrition and exposure to infections because of the poor socio-economic and hygiene conditions (Martorell 1985, Waterlow 1988, Eveleth and Tanner 1990, Gopalan 1992, Newmann and Harrison 1994, Norgan 1999, Floyd 2000).

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However, it is still not clear whether improvement in growth and nutritional status of children may also be due to the intermixture between populations through the geographical movement of individuals, or migration. Many studies pertaining to the differences between migrants and non-migrants have revealed that improvement in environmental quality is the main factor for the better growth and development of the former (Shapiro 1939, Goldstein 1943, Lasker 1952, Lasker and Evans 1961, Lasker *et al.* 1990, Bogin 1995, 1998, 1999). But little is known about the effects of heterosis, or hybrid vigour, on growth and development of children, especially after allowing for socio-economic differences (Chung *et al.* 1986, Livshits *et al.* 1987). It is likely that heterosis may have taken place as a result of migration, thereby increasing the frequency of heterozygotes and in turn accelerating growth and development of the hybrid children (Susanne *et al.* 1998). In other words, the effect of migration on growth of children may be related not only to better environmental quality, but also to heterosis and/or gene flow at times (Hulse 1957, Shapiro 1962). Thus, in the present paper an attempt has been made to deal with the growth in height, sitting height and subischial length of the urban Khasi girls of Northeast India with a view to understanding the possible role of heterosis in influencing physical growth and development.

2. Study population

The present study deals with the Khasi girls of Shillong, the capital of the hilly state of Meghalaya in Northeast India (25°47′ and 26°10′N latitude and 89°45′E and 92°47′E longitude). As described elsewhere (Khongsdier and Mukherjee 2003), the Khasis are one of the Indo-Mongoloid tribes in Northeast India. They speak the Monkhmer language, which belongs to the Austro-Asiatic group (Das 1978). They have been following the matrilineal system of society in which the rule of descent is reckoned through the female line. They are, by and large, an endogamous group, although intermarriages with other communities have also taken place. They are short to medium in stature when compared with other neighbouring groups including the Hindus and Muslims of Assam (Das *et al.* 1985, Khongsdier 2001).

The Khasis have been into contact from time to time with different peoples of different faiths from Bangladesh and other parts of India mainly through trade relationship. Their traditional religion is known as Niam Khasi, but about 65% of them have embraced Christianity, which was first spread by the Wales Presbyterian Missionaries in 1841. Some Khasis have also embraced Islam through matrimonial relationship with the Muslims who migrated from Bangladesh and other parts of India like Assam, West Bengal, etc. It is believed that the Khasis have come into contact with the Muslims since the 17th century through trade relationship with the Mughal emperors at Murshidabad (Irshad Ali 1992). In most cases, intermarriages took place between Khasi females and Muslim males. This may be due to the problem of reckoning the line of descent for the progeny of the marriage between Khasi males and immigrant Muslim females because of the matrilineal system of society. However, a Khasi female can marry a Muslim male by performing the Islamic rules, but her children are not treated as Khasis if they do not follow the matrilineal system of the society.

In the present study, we are concerned with the Khasi girls who were the offspring of both endogamous and exogamous marriages. For expediency, the girls of exogamous and endogamous marriages were referred to herein as hybrid (HB) and non-hybrid (NHB), respectively. The HB girls were the offspring of the first generation of intermarriages between Khasi females and immigrant Muslim males, irrespective of Muslim sects and places of birth. On the other hand, the NHB girls were the offspring of both parents who were from within the Khasi population. Unfortunately, anthropometric and genetic data were not available on Muslims of Meghalaya. However, from the anthropological point of view, Khasis and Muslims of Northeast India belong to the Mongoloid and Caucasoid racial groups, respectively. Considering the data reported by Das (1978) and Das *et al.* (1985), Khasis are shorter in stature and different in the distribution of certain genetic markers when compared with the neighbouring Muslims of Assam.

In Khasi hills, Muslims are mainly confined within the Shillong City. Therefore, the study was carried out in this city of the state of Meghalaya in Northeast India. The fieldwork was conducted by the second author in different intervals between November 1996 and February 1998 with the help of the local village council (Durbar Shnong) to assure the participation of people belonging to the three religious groups. No statistical sampling technique was applied for the selection of samples in the present study due to limited number of Muslim Khasi households. Data were collected from different areas (namely, Laban, Bishnupur, Garikhana and Lummawbah) of Shillong where both HB and NHB children were available. Special effort was made to include in our sample all available households of the Khasi Muslims who were willing to cooperate with the present study (Khongsdier and Mukherjee 2003).

3. Subjects and methods

This study consists of a cross-sectional sample of 1368 girls aged 3–18 years. The height and sitting height were measured with a Harpenden anthropometer (1 mm precision), following as far as possible the methods described in Weiner and Lourie (1981). No anthropometric data were taken on the parents. Data on age were based on school records and birth certificates given by parents. Also, data on monthly income of 588 households were collected directly from the head of household, and they were cross-checked taking into consideration some aspects of socio-economic conditions like housing condition, types of occupation, possession of property, and monthly expenditure. These households were then classified into three economic groups, namely low, middle and high income groups, taking into consideration the mean $-$ 4SD$\sqrt{N}$ of the per capita monthly income as the cut-off point (Khongsdier 2002).

The analysis was first carried out to present the descriptive statistics of the anthropometric variables like height, sitting height and subischial length (height minus sitting height) for both HB and NHB girls. Preece–Baines model 1 (PB1) was adopted for fitting the adjusted means of these anthropometric variables (Preece and Baines 1978), using Levenberg–Marquardt method through SPSS (version 10.0) and Origin Software (Version 7.0) for Windows. The mean age for each age group was used for performing the fitting. The age group was classified into 1-year intervals in which the girls of 2.50–3.49 and 3.50–4.49 years of age, for example, were grouped into 3.0 and 4.0 year age groups, respectively. For determining the differences between HB and NHB girls in respect to PB1 parameters, a likelihood ratio test was used by restricting the parameter estimates for the HB girls to the corresponding parameter estimates for the NHB girls. Then, the standard error of the difference between the two groups of girls was calculated from the asymptotic standard errors of parameter estimates for the two samples.

Although PB1 model is primarily meant for fitting individual-longitudinal data, its use in the present study was to estimate graphically some biological parameters (like adult size, age at maximum increment, or peak velocity and peak size velocity) with a view to understanding the nature of variation in growth patterns between HB and NHB girls. Of course, the application of this model to cross-sectional data has also been shown by many studies (Cameron *et al.* 1982, Lindgren and Hauspie 1989, Dasgupta and Das 1997, Milani 2000, Ward *et al.* 2001).

The differences in anthropometric characters due to heterosis, or hybridity, were tested by one-way analysis of covariance (ANCOVA) in which the corrected mean for household income and its standard error were computed for each age group of both HB and NHB girls, using SPSS for Windows (version 10.0). The significance of the differences between the two adjusted means was determined using Bonferroni's method. Thus, the effect of heterosis (H_s) on a given anthropometric variable was expressed as follows:

$$H_s = \left(\bar{X}_{HB} - \bar{X}_{NHB}\right) \Big/ \left[(SE_{HB})^2 + (SE_{NHB})^2\right]^{1/2}$$

where $\bar{X}_{HB}$ is the corrected mean for HB girls, $\bar{X}_{NHB}$ is the corrected mean for NHB girls, SE_{HB} is the standard error of the corrected mean for HB girls, and SE_{NHB} is the standard error of the adjusted mean for NHB girls. The income variable was expressed in terms of individual score, whether a given girl belonged to the low, middle or high income group (based on per capita monthly income of the household to which she belonged), which were coded as 1, 2 and 3, respectively.

4. Results

Table 1 gives the observed and adjusted means of height for household income. The adjusted means were smoothed using PB1 model of longitudinal data, and it is seen from figure 1 that HB girls were taller than NHB girls across age groups. The estimated adult size according to the PB1 model was about 150.3 cm for HB girls, which was about 0.8 cm higher than the observed value at the age of 18 years. On the other hand, the estimated adult height for NHB girls was about 147.0 cm, which was more or less the observed value. Thus, it indicates that both HB and NHB girls on the whole reached their adult height by the age of 18, but the HB girls were about 3.3 cm taller than the NHB girls, and this difference was more than twice its standard error (SE), or statistically significant (difference $\pm$ SE $= 3.29 \pm 1.04$, $p < 0.005$). However, the differences in respect of other estimated parameters of the PB1 fits were not significant, except the h_0 parameter (difference $\pm$ SE $= 2.98 \pm 0.98$, $p < 0.005$).

The estimate age at maximum increment, presumably considered as age at peak height velocity, was 12.1 years for HB girls and 12.3 years for NHB girls with the approximate height of 131.8 and 129.6 cm, respectively (table 1). Therefore, the adolescent growth spurt in height took place about 0.2 years earlier in HB girls when compared with NHB girls, although the peak height velocity was lower in the former (5.3 cm year^{-1}) than in the latter (5.6 cm year^{-1}). Figure 1 indicates that the velocity was higher in HB girls until the age of about 11 years, and thereafter it was higher in NHB girls until about the age of 14. Figure 1 further indicates that the larger stature in HB girls compared with NHB girls could be largely attributed to the differences in growth rate before and after the occurrence of adolescent growth spurt.

Table 1. Means, standard deviations and parameter estimates of height (cm).

HB girls					NHB girls				
Age (years)	*n*	Mean	SD	Adjusted mean	Age (years)	*n*	Mean	SD	Adjusted mean
3 (2.88)	25	84.47	4.85	85.31	3 (3.04)	67	84.60	3.79	84.29
4 (3.97)	23	90.78	4.05	91.43	4 (4.12)	64	90.37	5.79	90.13
5 (5.26)	23	96.60	5.01	96.96	5 (5.22)	63	96.16	5.93	96.03
6 (5.98)	26	102.65	4.23	103.02	6 (6.08)	63	100.12	4.51	99.96
7 (7.24)	25	107.48	6.54	108.03	7 (6.94)	68	105.70	4.93	105.49
8 (8.36)	22	112.51	4.11	112.88	8 (8.22)	62	109.96	4.89	109.82
9 (8.97)	26	117.42	4.64	117.54	9 (9.18)	60	114.55	5.75	114.49
10 (10.12)	21	120.71	4.40	120.96	10 (10.28)	58	117.64	4.90	117.55
11 (11.24)	19	125.56	3.38	125.79	11 (11.27)	61	122.82	3.94	122.75
12 (12.34)	22	133.70	3.89	133.81	12 (12.24)	63	130.93	4.07	130.89
13 (13.15)	21	137.48	4.12	137.86	13 (13.24)	66	134.71	3.60	134.59
14 (13.97)	25	141.50	4.38	141.48	14 (14.01)	62	139.76	5.25	139.77
15 (15.26)	26	146.31	3.90	146.26	15 (14.90)	63	142.87	5.32	142.89
16 (16.12)	22	148.10	3.92	148.48	16 (15.88)	62	145.43	5.77	145.30
17 (17.26)	17	148.79	6.22	149.43	17 (17.02)	59	146.58	6.41	146.39
18 (18.11)	22	149.18	5.21	149.49	18 (18.12)	62	146.85	5.41	146.74

	PB1 parameters				
Category	$h_0 \pm$ SE	$h_1 \pm$ SE	$s_0 \pm$ SE	$s_1 \pm$ SE	$\theta \pm$ SE
HB girl	138.52 ± 0.756	150.25 ± 0.810	0.805 ± 0.105	0.098 ± 0.006	13.30 ± 0.205
NHB girl	135.54 ± 0.623	146.96 ± 0.654	0.942 ± 0.103	0.099 ± 0.005	13.26 ± 0.152
Difference ± SE	2.98 ± 0.980*	3.29 ± 1.041*	0.137 ± 0.147	0.001 ± 0.008	0.04 ± 0.260
Biological variables					
Age at peak velocity (years	12.1		12.3		
Height at peak velocity (cm)	131.8		129.6		
Peak height velocity (cm year^{-1})	5.3		5.6		
Final height (cm)	150.3		147.0		

Values in parentheses indicate mean age.
*$p < 0.05$.

Like the case of height, the observed and adjusted means of sitting height were markedly higher in HB girls than in NHB girls across age groups (table 2). This can also be seen from the distance curve fitted to the adjusted means according to the PB1 model (figure 2). It shows that both HB and NHB girls reached their adult size of sitting height at about the age of 18, although the estimated adult size was significantly higher in HB than in NHB girls (difference ± SE = 1.84 ± 0.81, $p < 0.05$). Also, the estimated age at peak velocity was more or less the same in both HB (13.1 years) and NHB girls (13.2 years). Figure 2 demonstrates that the velocity derived from the fitted curve was higher in HB than in NHB girls from 3 to about 14 years, and thereafter it was slightly higher in the latter. Thus, unlike the case of height, HB girls outran NHB girls in acceleration rate until the adolescent period, and thereafter it tilted in favour of NHB girls. The higher sitting height in HB girls was mainly attributed to their higher growth velocities before and during the adolescent period.

As for lower extremity or subischial height, the PB1 fits to the adjusted means for household income indicate that both HB and NHB girls were by and large similar in subischial length from 13 to 15 years of age, although the former surpassed the latter at many ages (figure 3). As in the case of height and sitting height, the difference between HB and NHB girls in respect of estimated adult size was statistically

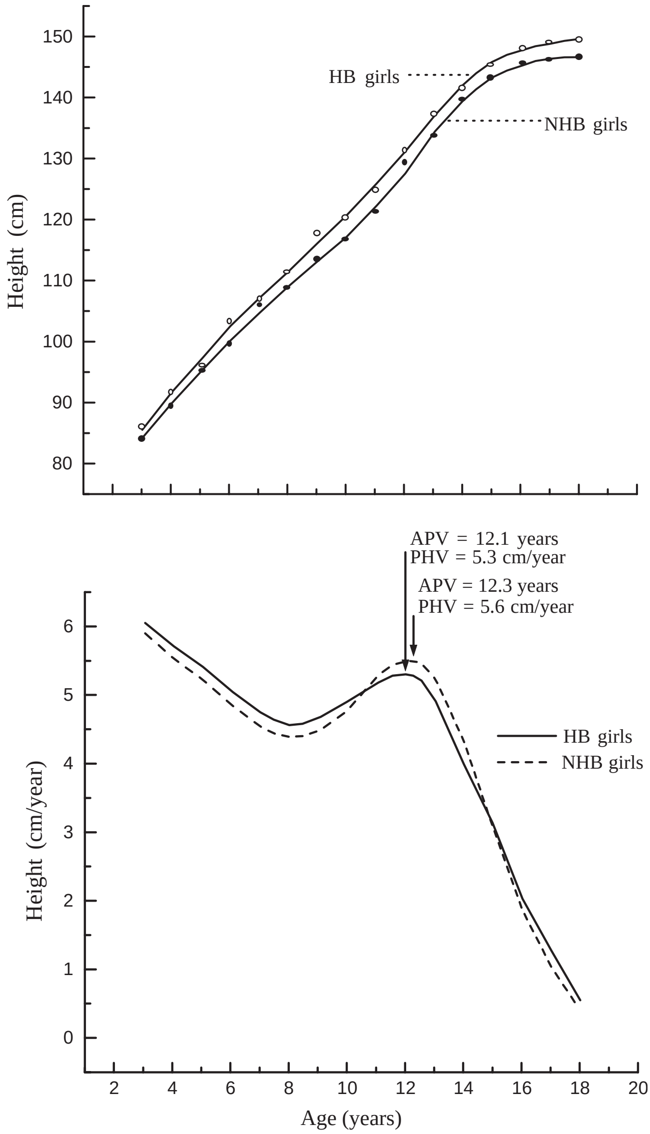

Figure 1. Upper panel: distance curves for height (smooth curves are PB1 fits to adjusted means). Lower panel: velocity curves (first derivative of the fitted function) indicating age at peak velocity (APV) and peak height velocity (PHV).

significant (table 3). Also, the estimated age at peak velocity was much lower in HB girls (10.5 years) than in NHB girls (11.9 years). It can be also observed from figure 3 that the velocity was higher in NHB girls from 3 to 4, and about 10 to 14 years of age and thereafter it tilted in favour of HB girls. Thus, it indicates that the higher height velocity in NHB girls from 11 to 14 years of age was mainly due to their higher growth rate in subischial length at that time. Notwithstanding, it indicates that the subischial length reached its peak earlier than the total height and/or sitting height for both HB and NHB girls. This observation seems to be consistent with those earlier findings on other populations (Tanner 1978, Dasgupta and Das 1997, Begum and Choudhury 1999).

Table 2. Means, standard deviations and parameter estimates of sitting height (cm).

HB girls					NHB girls				
Age (years)	n	Mean	SD	Adjusted mean	Age (years)	n	Mean	SD	Adjusted mean
3 (2.88)	25	46.16	2.32	46.61	3 (3.04)	67	46.46	2.53	46.30
4 (3.97)	23	50.11	2.71	50.27	4 (4.12)	64	49.25	3.79	49.19
5 (5.26)	23	52.75	2.88	52.94	5 (5.22)	63	51.77	4.24	51.70
6 (5.98)	26	55.92	2.80	56.22	6 (6.08)	63	54.17	2.89	54.05
7 (7.24)	25	57.53	4.10	57.77	7 (6.94)	68	56.74	3.34	56.66
8 (8.36)	22	59.28	2.41	59.42	8 (8.22)	62	57.98	2.61	57.93
9 (8.97)	26	62.35	2.76	62.40	9 (9.18)	60	60.91	3.13	60.88
10 (10.12)	21	63.20	3.08	63.37	10 (10.28)	58	61.41	4.27	61.34
11 (11.24)	19	65.78	3.01	66.02	11 (11.27)	61	64.20	2.79	65.12
12 (12.34)	22	70.13	2.52	70.19	12 (12.24)	63	67.95	3.17	67.93
13 (13.15)	21	71.45	2.25	71.79	13 (13.24)	66	69.14	3.54	69.04
14 (13.97)	25	74.30	2.78	74.29	14 (14.01)	62	72.88	3.47	72.88
15 (15.26)	26	77.34	3.19	77.30	15 (14.90)	63	74.69	3.90	74.70
16 (16.12)	22	78.41	2.71	78.56	16 (15.88)	62	76.55	3.32	76.49
17 (17.26)	17	78.84	3.78	79.11	17 (17.02)	59	77.30	3.95	77.22
18 (18.11)	22	78.95	2.88	79.20	18 (18.12)	62	77.29	3.42	77.20

	PB1 parameters				
Category	$h_0 \pm$ SE	$h_1 \pm$ SE	$s_0 \pm$ SE	$s_1 \pm$ SE	$\theta \pm$ SE
HB girls	73.57 ± 0.448	79.46 ± 0.528	0.930 ± 0.156	0.095 ± 0.006	13.66 ± 0.236
NHB girls	71.94 ± 0.507	77.62 ± 0.607	0.959 ± 0.178	0.094 ± 0.007	13.82 ± 0.262
Difference ± SE	1.63 ± 0.677*	1.84 ± 0.805*	0.029 ± 0.237	0.001 ± 0.009	0.16 ± 0.353
Biological variables					
Age at peak velocity (years)		13.1		13.2	
Size at peak velocity (cm)		71.5		69.9	
Peak size velocity (cm year^{-1})		2.9		2.7	
Final sitting height (cm)		79.5		77.6	

Values in parentheses indicate mean age.
*$p < 0.05$.

It is obvious from the above analyses that there were marked differences between HB and NHB girls in respect of height and its segments, which might be due to both genetic and environmental factors. Therefore, an attempt has been made to show in table 4 the calculated values of H_s after removing the effect of household income. The table shows that H_s values, which were equivalent to the differences between adjusted means, were significant at many ages with regard to height and sitting height. It is likely that these differences in growth pattern of HB and NHB girls might be associated with heterosis and/or gene flow. However, this study failed to find any significant difference in the three anthropometric variables of the HB and NHB girls belonging to the lower age groups, thus indicating the insignificant effect of hybridity on growth of children below 5 years of age. Also, there were insignificant differences between HB and NHB girls in respect of subischial length for many age groups, thereby suggesting a smaller susceptibility of the lower segment of the body to heterosis and/or genetic factors.

5. Discussion

In general, this study has revealed that both HB and NHB girls had reached their adult sizes of height, sitting height and subischial length by the age of 18. However, HB girls were taller than NHB girls across ages, and such a greater stature in HB

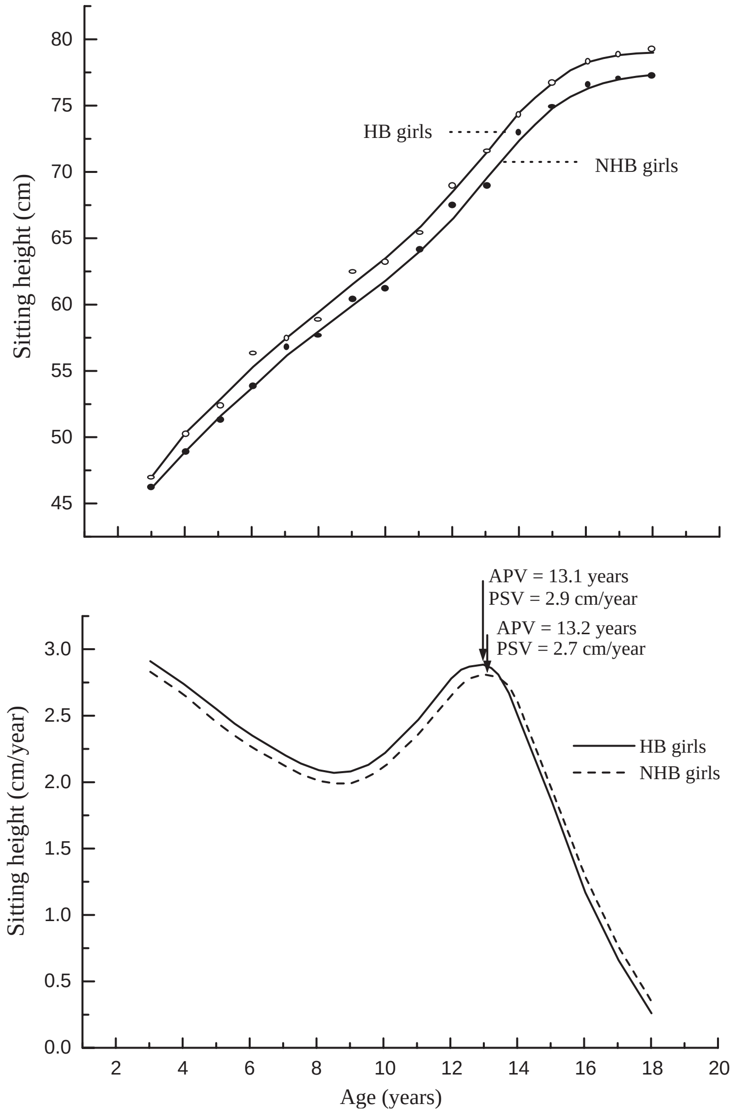

Figure 2. Upper panel: distance curves for sitting height (smooth curves are PB1 fits to adjusted means). Lower panel: velocity curves (first derivative of the fitted function) indicating age at peak velocity (APV) and peak size velocity (PSV).

girls was likely attributed to their greater velocities before the adolescent period. Both the groups were by and large similar in age at peak velocity for height and sitting height, despite the marked difference in respect of subischial length. The velocities were lower in NHB girls than in HB girls especially before the adolescent period, although the former surpassed the latter from about 11 to 14 years of age for height and subischial length, and 13 to 18 years for sitting height. Such a higher acceleration rate of height in NHB girls from 11 to 14 years of age was due to their higher velocity in subischial length at that time. In short, it is obvious from this study that HB girls were different from NHB girls in respect of the growth patterns of height, sitting height and subischial length.

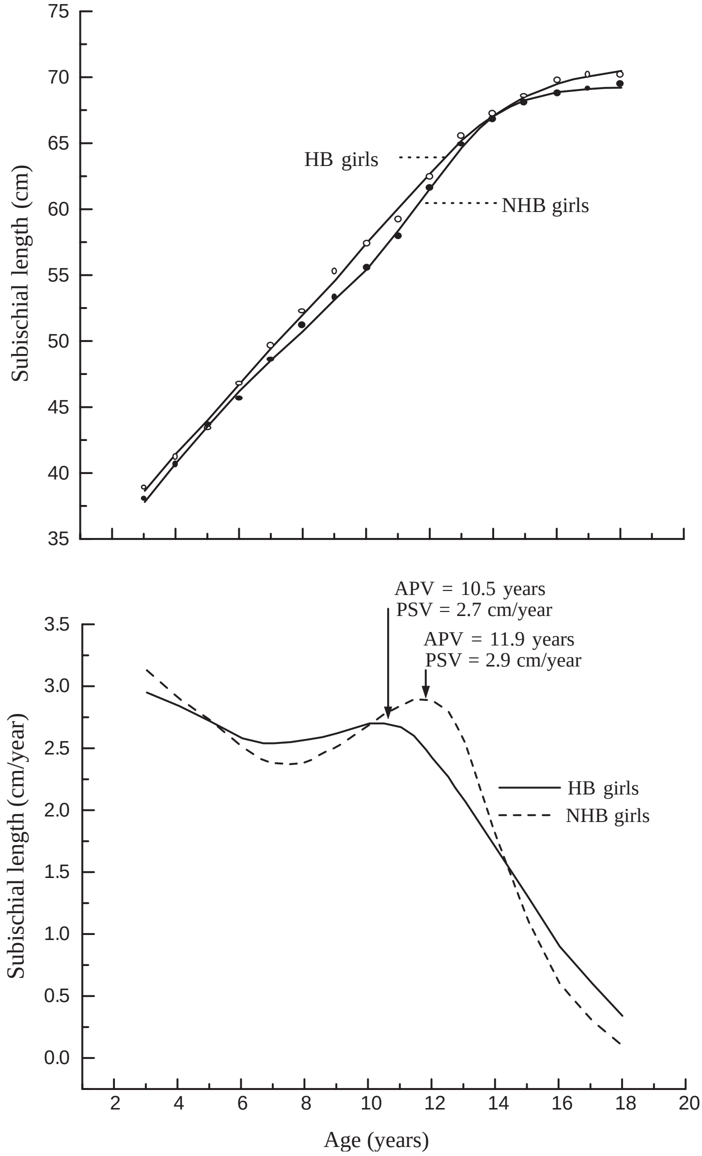

Figure 3. Upper panel: distance curves for subischial length (smooth curves are PB1 fits to adjusted means). Lower panel: velocity curves (first derivative of the fitted function) indicating age at peak velocity (APV) and peak size velocity (PSV).

The H_s values indicate that there were no significant differences in the three anthropometric variables between HB and NHB girls of below 6 years of age. Thus, the present findings may have two major implications. One is related to the observation that children below 5 years of age are more sensitive to environmental factors like nutrition and infections than to genetic factors (Martorell and Ho 1984, Cameron 1996, Frongillo *et al*. 1997, UNICEF 1998, Measham and Chatterjee 1998, Norgan 1999, Rice *et al*. 2000, de Onis *et al*. 2000, Bhandari *et al*. 2002). Second, the role of genetic factors like heterosis and/or gene flow cannot be completely ruled out if we take into consideration the differences between HB and NHB girls in the

Table 3. Means, standard deviations and parameter estimates of subischial length (cm).

HB girls					NHB girls				
Age (years)	n	Mean	SD	Adjusted mean	Age (years)	n	Mean	SD	Adjusted mean
3 (2.88)	25	38.31	3.39	38.70	3 (3.04)	67	38.14	2.64	37.99
4 (3.97)	23	40.67	2.77	41.16	4 (4.12)	64	41.12	4.02	40.94
5 (5.26)	23	43.85	2.58	44.02	5 (5.22)	63	44.39	5.30	44.33
6 (5.98)	26	46.73	2.83	46.80	6 (6.08)	63	45.94	3.06	45.91
7 (7.24)	25	49.96	4.39	50.22	7 (6.94)	68	48.59	3.14	48.49
8 (8.36)	22	53.23	2.50	53.46	8 (8.22)	62	51.98	2.91	51.90
9 (8.97)	26	55.08	2.49	55.14	9 (9.18)	60	53.64	3.51	53.61
10 (10.12)	21	57.52	2.37	57.59	10 (10.28)	58	56.23	4.13	56.21
11 (11.24)	19	59.77	2.85	59.77	11 (11.27)	61	58.63	2.74	58.63
12 (12.34)	22	63.56	2.58	63.62	12 (12.24)	63	62.98	3.17	62.96
13 (13.15)	21	66.03	2.10	66.07	13 (13.24)	66	65.57	2.71	65.55
14 (13.97)	25	67.20	3.06	67.19	14 (14.01)	62	66.88	3.49	66.89
15 (15.26)	26	68.97	2.81	68.95	15 (14.90)	63	68.18	3.33	68.19
16 (16.12)	22	69.70	2.62	69.92	16 (15.88)	62	68.88	5.29	68.80
17 (17.26)	17	69.95	4.81	70.32	17 (17.02)	59	69.28	4.77	69.17
18 (18.11)	22	70.22	3.43	70.28	18 (18.12)	62	69.57	3.80	69.54

	PB1 parameters				
Category	$h_0 \pm$ SE	$h_1 \pm$ SE	$s_0 \pm$ SE	$s_1 \pm$ SE	$\theta \pm$ SE
HB girls	63.97 ± 0.901	71.05 ± 0.609	0.600 ± 0.111	0.089 ± 0.013	12.46 ± 0.427
NHB girls	63.50 ± 0.276	69.36 ± 0.246	0.972 ± 0.090	0.104 ± 0.005	12.57 ± 0.135
Difference ± SE	0.47 ± 0.942	1.69 ± 0.657*	0.372 ± 0.143*	0.015 ± 0.014	0.11 ± 0.448
Biological variables					
Age at peak velocity (years)		10.5		11.9	
Size at peak velocity (cm)		58.9		61.1	
Peak size velocity (cm/year)		2.7		2.9	
Final subischial length (cm)		71.1		69.4	

Values in parentheses indicate mean age.
* $p < 0.05$.

higher age groups after allowing for household income, and that these two groups of girls were living within the same ecological setting.

There is no denying the fact that socio-economic factors, especially household income, are very important in influencing growth and nutritional status of children in developing countries. But it is also true that growth is subjected to the genetic influence as well. There have been substantial reports that 'children tend to grow along a genetically predetermined growth channel', i.e. considering growth as 'a target-seeking or self-stabilising process' (Hauspie and Susanne 1998). Thus, although empirical evidence has indicated that children of all major population groups are likely to have similar genetic potential, it does not mean that all population groups are so genetically homogeneous, thereby possessing the same genetically target of growth (Ulijaszek 1994). For instance, it is unlikely that the NHB girls of the present study would follow the 50th percentile of the US National Center for Health Statistics (NCHS) growth references, recently revised (Kuczmarski *et al.* 2000), and reach the adult height of 163.34 cm, although we were to assume that their present environment was not ideal. It is seen from figure 4 that the PB1 curve for NHB girls was below that for HB girls, and it was more or less in the fifth percentile of the NCHS growth references from 3 to about 5 years of age. Thereafter,

Table 4. H_s values for height, sitting height and subischial length.

	Height (cm)		Sitting height (cm)		Subischial length	
Age (years)	H_s	*p*-value*	H_s	*p*-value*	H_s	*p*-value*
3	1.085	0.281	0.539	0.591	1.033	0.304
4	1.001	0.320	1.215	0.228	0.247	0.806
5	0.682	0.497	1.303	0.196	0.266	0.791
6	3.096	0.003	3.548	0.001	1.244	0.216
7	2.036	0.045	1.332	0.186	2.088	0.040
8	2.619	0.011	2.321	0.023	2.237	0.028
9	2.442	0.017	2.162	0.033	2.051	0.042
10	2.826	0.006	1.996	0.049	1.425	0.158
11	3.996	0.000	2.722	0.008	2.416	0.018
12	3.087	0.003	3.083	0.003	0.897	0.372
13	3.546	0.001	3.392	0.001	0.780	0.437
14	1.478	0.143	1.824	0.072	0.389	0.698
15	3.159	0.002	3.247	0.002	1.038	0.302
16	2.469	0.016	2.636	0.010	0.950	0.345
17	1.868	0.066	1.794	0.077	0.908	0.367
18	2.210	0.030	2.781	0.007	0.799	0.426

* Adjusted according to Bonferroni's method.

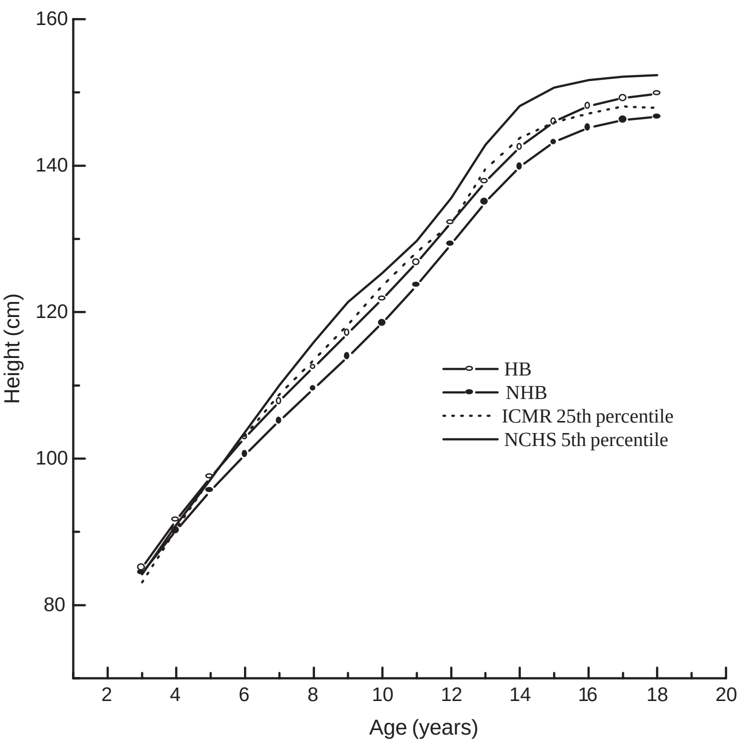

Figure 4. PB1 curves for heights of HB and NHB girls compared with NCHS and ICMR growth references.

it was below the 5th and 25th percentiles of the NCHS and Indian Council of Medical research (ICMR 1972) growth references, respectively. On the other hand, the PB1 curve for HB girls was more or less similar to the fifth percentile of the NCHS growth references from 3 to 6 years, and it was comparable to the 25th percentile of the ICMR growth references from the age of 6 onwards. During the 1960s, Das (1978) reported that the mean height ($\pm$SD) of adult females in this population was 146.42 ± 4.64 cm, which is about 1.08 cm lower than the adult stature predicted by the PB1 model for the NHB girls of the present study. If this difference is indicative of a secular trend, it does suggest the improvement in socio-economic condition of the study population. Thus, the better growth performance of HB girls compared with NHB girls after allowing for household income might be associated with genetic mechanisms like heterosis and/or gene flow, although effects of other socio-economic factors cannot be totally ruled out. This observation has also been made elsewhere with regard to growth and nutritional status of boys (Khongsdier and Mukherjee 2003).

Heterosis is believed to be an essential phenomenon that contributes to high yield in many crop species and maintains the balanced polymorphism in a population. Thus, it is related to 'adaptive superiority of heterozygotes over homozygotes' (Dobzhansky 1951). For example, it is an established fact that individuals who are heterozygous for haemoglobin S ($Hb\beta^A/Hb\beta^S$) have a higher Darwinian fitness than the individuals with either normal homozygosity ($Hb\beta^A/Hb\beta^A$) or abnormal homozygosity ($Hb\beta^S/Hb\beta^S$) in environments where malaria is endemic. Heterosis was first observed in animals and later in plants during the 19th century, but little is known about its genetic basis, and it has been a subject of debate for many years (Stuber *et al.* 1992, Mitchell-Olds 1995, Xiao *et al.* 1995).

It was once well known that the tall and vigorous Pitcairners of the Pitcairn Island in the Pacific were the products of the cross between the Bounty mutineers and Tahitian women (Shapiro 1962, Garn 1965). Hulse's (1957) study of the individuals of endogamous marriages in the Ticino canton of Switzerland compared with their relatives of exogamous marriages in California is one of the classical studies concerning the role of heterosis. He suggested that the taller stature of the offspring of exogamous marriages in California compared with those in Switzerland was due to heterosis. A study of six cephalometric measurements among children in Hawaii has also revealed the significant effect of hybridity on bizygomatic breadth, although it was insignificant in respect of other measurements (Chung *et al.* 1986). Also, more recent studies have shown the insignificant effect of such hybrid vigour (Lasker *et al.* 1990). Moreover, studies of the differences between migrant and non-migrant populations revealed that the migrant children were heavier and taller than the non-migrant children (Boas 1912, Shapiro 1939, Goldstein 1943, Someswara Rao *et al.* 1954, Greulich 1957, Bogin 1995, Bogin and Loucky 1997, Bogin 1998). Such a better growth performance in migrant children was believed to be independent of heterosis, but it was mainly associated with the improvement in environmental conditions including better socio-economic status and medical facilities. Of course, the variance in anthropometric measurements like weight and height due to socio-economic inequality is likely to be greater than that due to heterosis, or genetic mechanisms (Khongsdier and Mukherjee 2003). But it is also possible that the effect of heterosis may be interpreted as a consequence of the differences in socio-economic status if proper allowances are not made. It may be suggested that the role of heterosis in influencing growth may be better understood by taking into consideration the intra-population variation in respect of anthropometric, genetic and socio-economic variables within the same ecological setting.

Although the present study is short of genetic and anthropometric data on both the parents, it may be mentioned that Khasis are shorter than Muslims and they

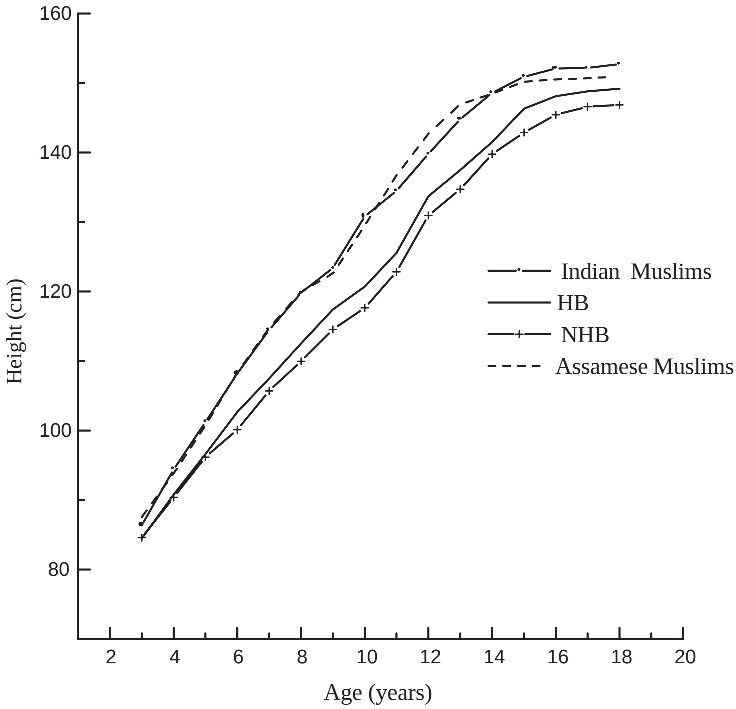

Figure 5. Mean heights of HB and NHB girls compared with Indian Muslim and Assamese Muslim girls.

belong to the Mongoloid racial group, whereas Muslims are Caucasians from an anthropological point of view (Das *et al.* 1985). It is also seen from figure 5 that HB girls were shorter than Indian Muslim girls (ICMR 1972) and the neighbouring Muslim girls of Assam (Begum and Choudhury 1999) across ages. On the other hand, both the groups of Muslim girls were, in general, similar in height especially below the age of 10 years. In view of these circumstances, does hybridization or intermixture bring about negative and/or positive results? If one assumes that the Muslims of Shillong are similar to the neighbouring Muslims of Assam, it is obvious that the HB girls of this study would be shorter than the original Muslim girls, but taller than the original Khasi girls, i.e. NHB girls. One possible explanations of such a phenomenon is that the mothers of HB girls were from the smaller stature population (i.e. Khasis), while the fathers belonged to the taller group (i.e. Muslims). This may have certain implications if we also take into consideration the findings of a longitudinal study of the hybrid groups in Israel, which has generated a mixed result (Livshits *et al.* 1987). The study has revealed that heterosis played a significant role in influencing the growth of infants who were the offspring of the intermixture between Yemen and Middle East individuals, but some other hybrid groups experienced certain disadvantages, while others were similar to the original groups. Therefore, it does require more information to have a better understanding of the role of heterosis and/or gene flow in patterning human growth and development since our knowledge in this regard has been based mostly on the anthropometric data of the migrant and non-migrant populations.

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Zusammenfassung. *Hintergrund*: Generell geht man davon aus, dass verbesserte Umweltbedingungen der Hauptfaktor für ein besseres Wachstum und einen besseren Ernährungsstatus der Kinder in Entwicklungsländern sind. Es ist jedoch noch nicht klar, ob diese bessere Wachstumleistung auch mit Heterosis und/oder Genfluß verbunden ist, welche aus der geographischen Wanderung von Individuen oder aus Migration resultieren.
Ziel: In dieser Arbeit wird versucht, den Einfluss von Heterosis auf das Wachstum der Körperhöhe und der Segmentlängen bei den Mädchen zu untersuchen.
Material und Methoden: Der vorgelegten Analyse liegt eine Querschnittsprobe der Khasi Mädchen von Shillong in Nordostindien zugrunde. Körperhöhe und Sitzhöhe wurden mit einem Harpenden Anthropometer mittels standardisierter Technik bei 1368 Mädchen im Alter zwischen 3 und 18 Jahre gemessen. Die Stichprobe wurde in zwei Gruppen unterteilt, die Mischlinge (HB) und Nichtmischlinge (NHB) genannt wurden. Anhand dieser Gruppen wurde der Einfluss von Heterosis mittels Kovarianzanalyse - mit Haushaltseinkommen als Kovariate - geprüft. Preece Baines Modell 1 (Preece und Baines 1978) wurde verwendet, um anhand der adjustierten Mittelwerte der Körperhöhe und der Segmente die Variation bei der Erwachsenhöhe, das Alter und die Größe bei der maximalen Wachstumsgeschwindigkeit zu schätzen.
Ergebnisse: Das Alter zum Zeitpunkt des maximalen Wachstumszuwachses bei der Körperhöhe (12 Jahre) und bei der Sitzhöhe (13 Jahre) stimmte bei den Mädchen in der HB- und NHB-Gruppe überein. Allerdings trat der maximale Wachstumszuwachs bei der subischialen Länge in der HB-Gruppe (10.5 Jahre) viel früher auf als in der NHB-Gruppe (11.9 Jahre). Die Ergebnisse weisen darauf hin, dass Mädchen der HB-Gruppe in allen Altersklassen größer waren als die der NHB-Gruppe. Dies ist hauptsächlich auf die größere Wachstumgeschwindigkeit bei den Mädchen der HB-Gruppe vor dem Jugendalter zurückzuführen. Heterosis, kontrolliert für das Haushaltseinkommen, stellt in vielen Altersgruppen zwischen 6 und 18 Jahren einen hoch signifikanter Einflussfaktor dar, obgleich dies bei der subischialen Länge nicht feststellbar ist.
Zusammenfassung: Da der Einfluss von Heterosis und/oder Genfluss auf das Wachstum und die Entwicklung von Kindern nicht vollständig ausgeschlossen werden kann (besonders nach dem 5. Lebensjahr, wenn die Variation in den Wachstumsmustern nicht nur durch Umwelteinflüsse, sondern auch durch genetische Einflüsse bedingt ist), sollten dazu weitere Studien durchgeführt werden.

Résumé. *Arrière-plan*: On pense généralement que l'amélioration de la croissance et du statut nutritionnel des enfants dans les pays en développement, est principalement due à l'amélioration de la qualité de l'environnement, mais il n'est toujours pas clair qu'il n'y ait pas également une association de cette meilleure croissance avec un effet d'hétérosis ou bien avec un flux génique résultant du mouvement géographique des individus ou de la migration.
But: Cet article a pour but d'évaluer l'effet de l'hétérosis sur la croissance de la stature des filles et des segments qui la composent.
Matériel et méthodes: l'analyse porte sur un échantillon transversal de filles Khasi de Shillong dans le nord-ouest de l'Inde. On a mesuré la stature et la taille-assis de 1368 filles âgées de 3 à 18 ans, avec un anthropomètre Harpenden, en suivant les techniques standard. L'échantillon a été scindé en deux groupes, les filles hybrides (HB) et non hybrides (NHB), afin d'estimer les effets de l'hétérosis par analyse de covariance, le revenu familial étant une covariable. Le modèle 1 de Preece Baines (Preece and Baines 1978) a été utilisé pour ajuster les moyennes affinées de la stature et de ses composants avec l'idée d'exprimer les variations de la stature adulte, l'âge à la vitesse de pic et la vitesse de pic.
Résultats: Les filles HB aussi bien que les NHB ont un âge de croissance maximum en stature (12 ans) et en taille-assis (13 ans) identique, bien que cet âge soit beaucoup plus précoce pour les premières (10,5 ans) que pour les secondes (11,9 ans) pour ce qui concerne la hauteur sub-ischiale. Les résultats indiquent que les filles HB sont plus grandes que les filles NHB à tous les âges, principalement par suite de leur plus grande vitesse de croissance avant l'adolescence. Après le facteur du revenu familial, l'effet induit par l'hétérosis sur la croissance est souvent hautement significatif entre 6 et 18 ans, bien qu'il ne soit pas clairement perceptible dans le cas de la hauteur sub-ischiale.
Conclusion: L'influence de l'hétérosis et des flux géniques sur la croissance et le développement des enfants ne peut pas être totalement ignorée, en particulier après l'âge de 5ans, quand la variation des modalités de la croissance n'est vraisemblablement plus associée à la seule qualité de l'environnement, mais aussi à des mécanismes génétiques.

Resumen. *Antecedentes*: Se piensa generalmente que la mejora en la calidad ambiental es el principal factor para el mejor crecimiento y estado nutricional de los niños en los países en vías de desarrollo. Sin embargo, aún no está claro si tal mejora en el crecimiento está también asociada con la heterosis y/o con el flujo génico que pueden ocurrir como resultado del movimiento geográfico de los individuos, o migración.

Objetivo: Este artículo intenta abordar los efectos de la heterosis sobre el crecimiento físico femenino en estatura y sus segmentos.

Sujetos y métodos: En el presente análisis se consideró una muestra transversal de chicas Khasi de Shillong, en el nordeste de la India. Se midió la estatura y la talla sentado de 1.368 chicas de 3 a 18 años de edad con un antropómetro Harpenden, mediante técnicas estandarizadas. Para comprobar los efectos de la heterosis, la muestra se dividió en dos grupos de chicas denominados híbrido (HB) y no híbrido (NHB), utilizando un análisis de covarianza con los ingresos de la familia como covariante. Se empleó el modelo 1 de Preece-Baines (Preece y Baines 1978) para ajustar las medias de estatura y sus segmentos, con el objeto de estimar la variación en la estatura adulta, la edad al pico de velocidad y el tamaño alcanzado en el pico de velocidad.

Resultados: Tanto las chicas HB como las NHB fueron similares en cuanto a las edades del máximo incremento estatural (12 años) y de la talla sentado (13 años), aunque el máximo incremento de la longitud subisquial fue más temprano en las primeras (10,5 años) que en las segundas (11,9 años). Los resultados indican que las chicas HB eran más altas que las NHB a todas las edades. Este mayor "estado antropométrico" de las chicas HB se debía principalmente a sus mayores velocidades de crecimiento antes del periodo adolescente. El efecto de la heterosis según los ingresos familiares fue altamente significativo en muchas edades desde los 6 a los 18 años, aunque no fue claramente perceptible en el caso de la longitud subisquial.

Conclusión: A la espera de posteriores estudios, no puede descartarse completamente el papel de la heterosis y/o del flujo génico en el crecimiento y desarrollo de los niños, especialmente después de los 5 años de edad, cuando la variación en los patrones de crecimiento parece estar asociada no solo con la calidad ambiental sino también con los mecanismos genéticos.