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ORIGINAL ARTICLE

Parameters of pubertal growth spurt in children and adolescents living at high altitude in Peru

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Age and peak height velocity;
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Preece-baines function

Abstract

Objectives: The aim was to estimate the pubertal growth height of children and adolescents living in a high-altitude region of Peru using the Preece-Baines model 1 (1 PB).

Methods: A cross-sectional study was conducted in schoolchildren from the department of Puno (Peru) between 3841 and 3874 masl. The age range was between 4 and 17 years. Standing height was evaluated. 1 PB was used to infer the mathematical and biological parameters of stature.

Results: Mathematical parameters estimated by the 1 PB model reflected small residual standard error (RSE) values in both sexes (0.25 in boys and 0.27 in girls). In boys, the age at which peak velocity was reached (APHV) was estimated at 13.21 ± 0.33years. While in girls it was 9.96 ± 0.26years ($p < 0.05$). In general, girls reached APHV (y) 3.25 years earlier than boys. On the other hand, the growth velocity of maximum height [APHV (cm/y)] of boys was higher (6.33 ± 6.06 cm/y) relative to girls (6.06 ± 0.32 cm/y). Estimated final adult height (EFAH) in boys was reached at 166.020 ± 0.99 cm and height at maximum growth velocity (HPHV) was 153.07 ± 0.67 cm, while in girls they were significantly lower (EFAH; 153.74 ± 0.44 cm and HPHV: 139.73 ± 0.84 cm).

Conclusions: This study showed that girls living in Puno at a high altitude in Peru reached APHV 3 years earlier than boys and at the same time reflected slower PHV. These results suggest that

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pubertal growth at high altitudes is slower in both sexes and especially in girls. Thus, modeling physical growth may be an important step in understanding the onset of puberty at different latitudes.

Introduction

Physical growth begins at fertilization and progresses through the prenatal, infant, early childhood and adolescent phases to be completed by the fusion of the epiphyseal growth plates.[1] The schooling age (6 to 20 years) is one of the important phases in the human life cycle because, during these years, the body changes significantly in size, structure, proportions and body composition.[2]

In fact, children grow at different rates and timing, where specific body parts demonstrate differential timing (the time at which a given growth event occurs) and tempo (the rate at which this growth event manifests itself).[3,4] During puberty, height growth varies according to chronological age and maturity status,[5] where girls average a maximum height velocity of 9 cm/year at the age of 12 years, and boys, on average, reach a maximum height velocity of 10.3 cm/year at the age of 14 years.[6]

These changes are influenced by a number of genetic and environmental factors. These have a significant impact on auxological parameters, which are often the anthropometric measures used to assess adolescent growth and development.

In general, the most appropriate parameter to indicate the onset of puberty is the age of take-off in both boys and girls[7] and is preferably determined from a longitudinal study rather than a cross-sectional study.[8] However, given the difficulties of conducting longitudinal studies, where they demand extended periods of time, often years or decades,[9] several recent studies have used cross-sectional samples for estimation of peak growth velocity and pubertal growth spurt parameters in children from various parts of the world, using the 1 Preece-Baines Model (1 PB).[10-12]

However, as far as is known, there are few studies that estimate biological parameters by means of mathematical models of children and adolescents living in regions of moderate and high altitude,[13-15] since high altitude areas of the world are characterized by hypobaric hypoxia, low temperatures, low relative humidity, high cosmic radiation and, in some cases, limited nutritional resources.[16] These characteristics cause a delay in linear growth, in addition, they present a prolonged growth period, a late and poorly defined growth spurt in relation to their sea-level peers.[17]

Consequently, based on the fact that all these conditions affect the growth and development of children, in such a way that slows down the maturation process and depresses physical growth,[16] it is possible that children living in Puno (Peru) at an altitude of 3820 m above sea level (masl) could reflect a delay in pubertal growth spurt parameters.

Therefore, the objective of this study was to estimate the pubertal growth spurt parameters of children and adolescents living in a high-altitude region of Peru using the Preece, Baines 1 PB model.

Materials and methods

Type of study and sample

A cross-sectional study was conducted on schoolchildren in the department of Puno (Peru). The population consisted of 7800 students (3750 boys and 4050 girls) at preschool (4 and 5 years), primary (6 to 11 years) and secondary (12 to 16 years) levels. The schoolchildren belonged to six districts of the department of Puno [(Lampa, 3.874 masl, n = 126), (Azángaro, 3.867 masl, n = 120), (Yunguyo, 3.857 masl, n = 149), (Huancané, 3.841 masl, n = 170), (Ilave, 3.841 masl, n = 150), and (Juliaca, 3.834 masl, n = 174)]. The sample size was 11.4 % [426 boys (5.4 %) and 463 girls (5.9 %)]. The number of sample elements for each stratum was directly proportional to the universal population according to age and sex (95 % CI).

All subjects were recruited from the main state school in each region. These students belonged to the lower middle class.[18] Schoolchildren in this region are generally identified as Indigenous and mestizo. The racial and ethnic ancestry of the schoolchildren in this area came from two geographical areas (Quechua and Aymara). They were defined as Indigenous if they had both surnames of their parents (native to the region) and mestizo if they had at least one surname of Spanish origin. In Peru, children have two surnames (the first is the father's and the second is the mother's). These data were provided by each of the schools and were used in the study through an inclusive and respectful approach to the identity of each schoolchild.

Access to basic services for this population according to the National Institute of Statistics of Peru (INEI)[19] was: water service (inside and outside the house) 47.2 %, sewage 35.7 %, and electricity 74.2 %. The economy is based on mining, agriculture, livestock, and tourism.

Puno is a department of Peru and is located at 3812 m above sea level, on the shores of Lake Titicaca (in the southeast of the country, on the Collao plateau) and borders the neighboring country of Bolivia (La Paz).

All schoolchildren who attended the day of the anthropometric evaluations and those who were born in each of the six provinces of the department of Puno were included in the study.

Schoolchildren who came from another neighboring geographic region, those born at low and moderate altitudes and whose parents did not authorize informed consent were excluded.

The study was conducted according to the Helsinki Declaration for Human Subjects and was approved by the local ethics committee (UNAP-100/2019). Parents and/or guardians signed consent for minors under 18 years of age.

Procedures

Data such as age, sex and school were recorded on an individual form. The height assessment was performed at the facilities of each school. A team of 4 evaluators with extensive experience in anthropometric evaluation went to each district and school to evaluate the height of children and adolescents. Evaluations were conducted in 2016 (in the months of April to June and August to December) from 8:30 a.m. to 1:00 p.m. Monday to Friday.

Standing height assessment was performed according to the protocol standardized by Ross, Marfell-Jones.[20] It was measured according to the Frankfurt plane and with the least amount of clothing possible (shorts, T-shirt and no shoes). A portable stadiometer (Seca Gmbh & Co. KG, Hamburg, Germany) with an accuracy of 0.1 mm was used. To determine the relative technical error of measurement (rTEM) of stature, it was evaluated twice (retest). It was applied to the whole sample, showing values lower than 1.1%.

The non-linear regression model 1PB[21] was used to infer the mathematical and biological parameters of height growth rate and growth spurt for both sexes.

Statistical analysis

The normal distribution of the data was verified using the Kolmogorov-Smirnov test. Descriptive statistics of mean, standard deviation (SD), standard error (SE), and ranges were calculated. Differences between men and women were verified using the *t*-test for independent samples. The 1 PB model was used to make inferences about mathematical and biological parameters. This model is adapted to studies of height growth in longitudinal and cross-sectional samples.[13,14] This nonlinear model has five parameters and is inferred by the following equation:

$$h = h_1 - \frac{2(h_1 - h_\theta)}{e^{s_0(t-\theta)} + e^{s_1(t-\theta)}}$$

Where: h_1: final height (cm), h_θ and θ: average height (cm), and age (years) for height on the decreasing slope of the PHV, s0 and s1, prepubertal and pubertal rate constants controlling height velocity (cm/years).

Calculations and graphs of the curves were obtained using the computer program implemented in R software. Significant differences were considered $p < 0.05$.

Results

The mean values and standard deviation of the height of children and adolescents, by age and sex, living at high altitude in Puno (Peru) can be seen in Table 1. The height growth curve of children and adolescents of both sexes can be seen in Figure 1. From 4 to 13 years of age there were no significant differences in both sexes ($p > 0.05$). However, differences in height growth patterns begin to appear from 14 to 18 years of age ($p < 0.05$).

The 1 PB model was successfully fitted to the cross-sectional data of children and adolescents living at high altitudes in Puno (Peru) (Table 2). The biological parameters of the sample were adjusted to the PB1 model. The residual standard error (RSE) reflects an adequate fit in both sexes (0.25 in boys and 0.27 in girls). In boys, the final height (hi) was reached at 166.020 ± 0.99 cm, while in girls at 153.74 ± 0.44 cm ($p < 0.05$). As for the height at the time reaching their maximum height velocity ($h\theta$) boys reached at 153.07 ± 0.67 cm and girls at 139.73 ± 0.84 cm ($p < 0.05$).

The biological parameters of APHV and PHV can be seen in Table 2 and were plotted in Figure 2. In boys, the age of peak velocity (APHV) was estimated at 13.21 ± 0.33 years, while in girls it was at 9.96 ± 0.26 years ($p < 0.05$). In general, girls reached APHV (y) 3.25 years earlier than boys. On the other hand, boys' PHV (cm/y) reached a higher growth velocity in height (6.33 ± 6.06 cm/y) relative to girls (6.06 ± 0.32 cm/y).

Table 1 Descriptive values (mean ± SD) of the height of children and adolescents living in Puno (Peru).

Age (y)	Boys			Girls		
	n	X	SD	n	X	SD
4	29	103.9	10.39	26	102.95	8.01
5	44	108.61	10.35	48	106.62	10.95
6	40	114.33	9.61	47	112.75	11.38
7	46	118.92	10.24	44	117.65	12.21
8	46	123.65	9.97	50	121.96	11.1
9	49	128.34	11.55	39	129.81	9.93
10	35	132.49	10.41	36	134.7	11.46
11	40	137.88	10.75	33	139.64	10.28
12	28	144.55	8.78	19	145.08	6.76
13	15	148.73	6.00	27	148.25	9.15
14	11	154.74	7.13	31	151.58	8.57
15	21	161.51	7.7	32	152.96	10.41
16	20	163.53	7.83	26	152.31	8.82
17	2	162.1	1.8	5	152.7	2.01

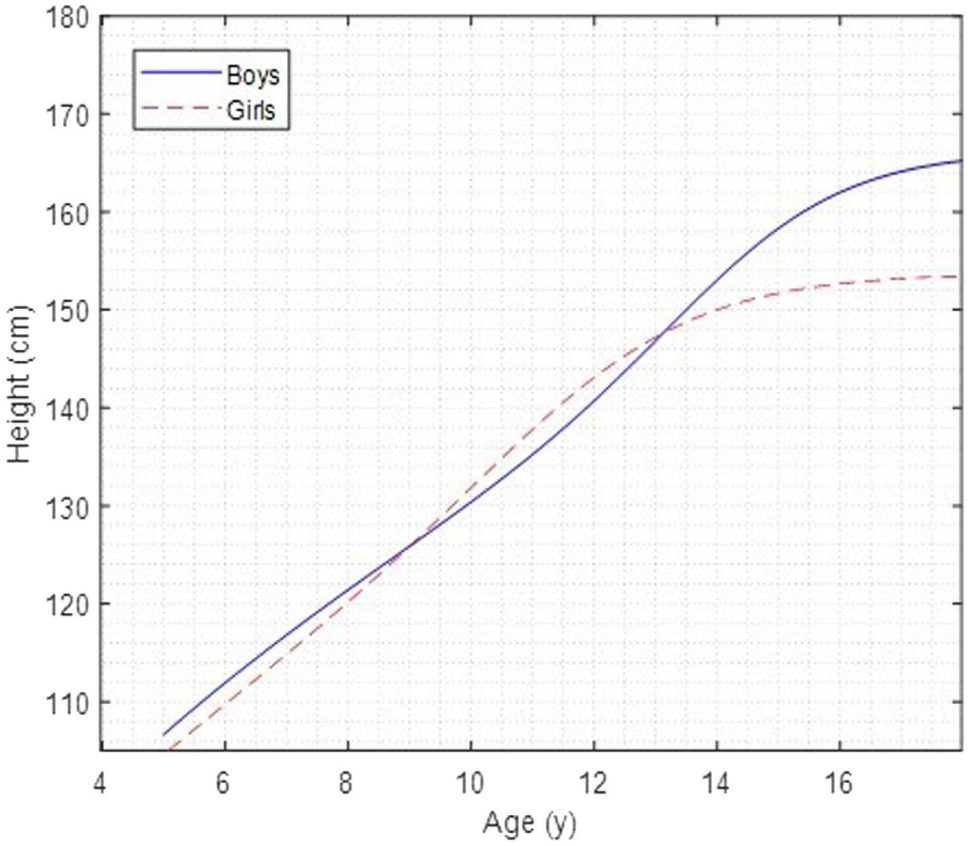

Figure 1 Height growth curve of children and adolescents of both sexes living in Puno (Peru).

Table 2 Mathematical and biological parameters of the height of children and adolescents of both sexes, estimated by the 1 PB model.

PB model parameters	Boys		Girls	
	X	SE	X	SE
Mathematical parameters				
s0	0.09	0	0.09	0.01
s1	0.81	0.06	0.69	0.05
θ	14	0.16	11.34	0.17
Hθ	153.07	0.67	139.73	0.84
h1	166.2	0.99	153.74	0.44
Residual SE	0.25		0.27	
Biological Parameters				
Age at peak velocity (y)	13.21	0.33	9.96	0.26
Peak height velocity (cm/y)	6.33	0.56	6.06	0.32

Legend: Age at peak velocity (APHV); Peak height velocity PHV (cm/y); Estimated final adult height (EFAH); Height at maximum growth velocity (HPHV = hθ); Residual Standard Error (RSE).

Discussion

This study aimed to estimate the pubertal growth spurt parameters of children and adolescents living at high altitudes in Peru using the 1 PB model. The findings of the study have reported that girls living at high altitudes in Puno, have reached APHVs at 9.96 $\pm$ 0.26 years, while in boys it was at 13.21 $\pm$ 0.33years. These results indicate that girls in Puno reached APHV 3.25 years earlier than boys, which represents a greater difference than what is reported in the literature.[6,8] In fact some studies, highlight that girls generally reach APHVs two years earlier than boys.[22,23] However, this wide difference in years verified in this study coincides with that reported in some recent studies carried out at moderate altitudes in Colombia.[15] As well as at high altitude in Peru, investigating in the province of Huancayo, specifically in the department of Junín (Peru).[14]

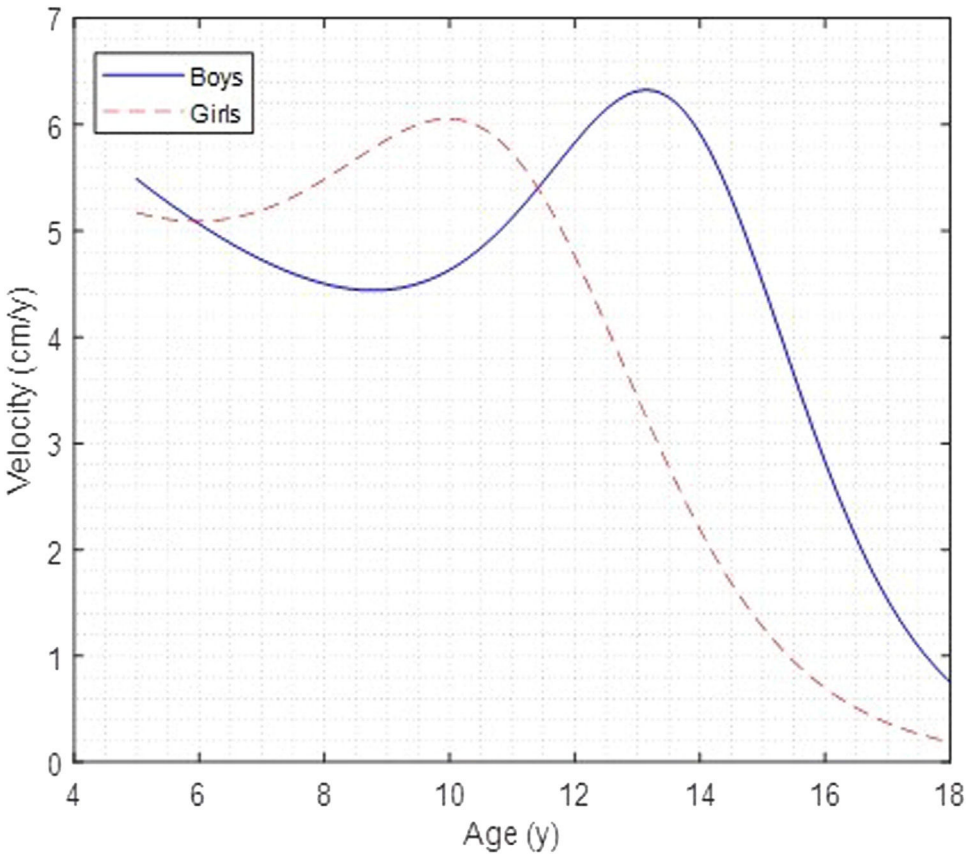

Figure 2 Maximum height velocity curves of children and adolescents of both sexes living in Puno (Peru).

In essence, what is striking is that the girls from Puno showed an unusually early onset of adolescence according to PB1, perhaps this fact is due to the lack of suitability of using PB1 in cross-sectional studies as suggested by Zemel et al.[24] This could reflect problems of empirical validity in women when analyzed in cross-sectional samples. However, we do not rule out the possibility that girls in Puno, being of lower middle socioeconomic status, the adolescent outbreak could be small in size. It could even be a common characteristic of girls living at high altitudes. In this context, a longitudinal study could help to clarify these aspects analyzed in this research.

However, the pattern observed in moderate and high-altitude children and adolescents from Colombia[15] and Peru[14] are similar to those reported in this study. This behavior could be characterized as typical of these regions, where girls reached PHV 3 years earlier than boys and not two years as has been described in the literature. In fact, recent epidemiological evidence suggests that the onset of puberty hasadvanced in humans in recent years, the mechanisms of which are still unknown.[25] Therefore, more studies are needed to diagnose precocious puberty, for which hormonal tests are necessary. In addition, analysis of clinical data related to the signs of pubertal onset, can be confirmed by means of the GnRH reference pattern.[26]

In addition, in terms of PHV, boys from Puno showed a higher growth rate in height (6.35 cm/y) relative to girls (6.05 cm/y) of the same altitude, which, are consistent with some studies conducted in moderate and high altitude geographic regions,[14,23] in which boys reflect a higher growth velocity than their girl counterparts and at the same time, these children of both altitude sexes evidenced a slower PHV than their similar from other geographic regions of the world.[10,11]

The findings obtained in the present study demonstrate that children and adolescents living at high altitude in Puno (3820 m) present a pattern typical of high-altitude regions, so this information may help to understand the pubertal growth spurt and provide a new perspective on the etiology of linear growth in relation to other latitudes, especially in children. In addition, this information may serve as a general indicator of child health, both at sea level and at high altitudes.

Consequently, given the importance of studying the linear growth of children and adolescents from high altitudes, when compared to other studies from moderate altitude regions of Colombia,[13] and from low altitudes,[10,11] children from Puno (Peru) reflected a relatively slower growth. In addition, HPHV and EFAH were reached at lower statures in relation to the studies indicated above.

Therefore, despite the relevance of the findings obtained in this study, the presence of physical growth retardation in children and adolescents of moderate[27] and high altitude in Peru[28] remains an important public health problem, despite the fact that, in recent years, Peru has been improving its economic income in relation to neighboring countries.[29]

Overall, this study provides broad advantages on the biological parameters of height growth of children living at high altitudes, so far as known, it is the first study conducted in Peru at 3820 m above sea level, moreover, the results

obtained in this study can be used as a baseline for multiple comparisons in the future, e.g., to verify secular growth trends, as well as to compare with other altitude studies with similar characteristics, and even recently Lee[30] highlights that human modeling tools based on anthropometric data and morphological characteristics can be applied for industrial purposes (for clothing and other human-oriented design processes).

However, without prejudice to the above, it is necessary to highlight some limitations that should be considered for future studies. First, this study used cross-sectional data to estimate the biologic parameters of physical growth, so it is possible that the results obtained do not allow verification of intra- and interindividual changes, so it is necessary to design a longitudinal study to verify the real pattern of physical growth of these young people. Secondly, it is necessary to consider in future studies children living in different altitude regions of Peru, since there are cities located at sea level (such as Lima at 154 m), at moderate altitude (2320 m in Arequipa), and at high altitude (3820 m in Puno and 4300 m in Cerro de Pasco). Thirdly, it is necessary to design studies comparing children and adolescents living at altitude and coming from medium and low socioeconomic conditions with the intention of estimating biological parameters.

And fourth, it is important to estimate the biological parameters of physical growth not only using the 1 PB model but also to explore other clinical, biochemical, and radiological methods, whose information could be relevant to complement the present findings.

Conclusions

In conclusion, this study showed that girls living in high Puno in Peru reached APHVs 3 years earlier than boys and at the same time reflected a slower PHV than boys. These results suggest that pubertal growth at high altitudes is slower in both sexes and especially in girls. Thus, modeling physical growth may be an important step in understanding the onset of puberty at different latitudes.

Authors' contributions

Conceived and designed the experiments: Marco Cossio-Bolaños, Rossana Gómez-Campos, Enio Vaz Ronque.

Performed the experiments: Jose Fuentes-Lopez, Lucila Sanchez-Macedo, Eliseny Vargas-Ramos, Margot Rivera-Portugal.

Analyzed the data: Marco Cossio-Bolaños, Rossana Gómez Campos, Rubén Vidal Espinoza, Enio Vaz Ronque, Luis Felipe Castelli Correia de Campos, Juan Minango Negrete.

Contributed reagents/materials/analysis tools: Jose Fuentes-Lopez, Lucila Sanchez Macedo, Eliseny Vargas Ramos, Margot Rivera Portugal.

Drafted the paper: Marco Cossio-Bolaños, Rossana Gómez Campos and Rubén Vidal Espinoza.

Conflicts of interest

The authors declare no conflicts of interest.

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