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ORIGINAL ARTICLE

Height growth study of healthy children and adolescents from Córdoba, Argentina

Estudio del crecimiento de la estatura en una muestra de niños, niñas y adolescentes sanos de Córdoba, Argentina

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What do we know about the subject matter of this study?

In the absence of longitudinal studies, the Preece-Baines model 1 allows obtaining the mean growth curve of height in a population from a cross-sectional sample.

What does this study contribute to what is already known?

The Preece-Baines Model 1 allowed to satisfactorily estimate the peak age of the growth spurt, the growth rate at that point, and the expected final adult height in a sample of healthy children and adolescents in Córdoba, Argentina.

Abstract

Objective: Based on a sample of children and adolescents of both genders, our objective is to describe height growth, estimate the peak age at growth spurt, growth rate at this point, the final adult height expected, and differential patterns. **Subjects and Method:** A cross-sectional study was conducted using demographic, clinical, and anthropometric data collected prospectively from children and adolescents of both sexes between 2015 and 2016. Height percentiles were calculated using the LMS (skewness, median, and coefficient of variation) method and then adjusted using the Preece-Baines model 1. **Results:** We evaluated 861 participants (484 girls, 377 boys), aged between 2 and 18 years. The estimated peak age at growth spurt (h_θ) was 13.6 years in boys and 11.0 years in girls, with a peak growth rate (V_2) at this point of 6.4 cm/year for both sexes. The mean expected adult height (h_1) was 173.7 cm in boys and 160.0 cm in girls. **Conclusions:** Preece-Baines model 1 provides satisfactory estimates for the peak age at growth spurt, peak growth rate at this point, and final expected adult height.

Keywords:
Children;
Adolescents;
Growth;
Height

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Introduction

It is essential to know the height of the reference population in order to assess linear growth in children and adolescents[1,2]. Since growth occurs simultaneously with pubertal development, there is also interest in knowing the age at the beginning and peak of the growth spurt, and in determining the extent and speed of growth expected at those points during the assessment of growth and development[3].

Although longitudinal studies of growth and development are the ideal method for describing the dimension and speed of growth[4], different mathematical models can also be used to understand the variations in the height growth of a population through specific functions in cross-sectional studies[5]. The Preece-Baines 1 (PB1) model fits for the study of height growth and has been applied to describe it in cross-sectional samples from childhood to late adolescence[6-8]. The PB1 includes mathematical and biological parameters to determine the age of starting, magnitude, and speed of growth during the different stages of development until reaching adult height.

As far as we know, there are no previous researches regarding height growth in a sample of the present-day Argentine population in longitudinal studies nor by adjusting the data with the PB1 model in transversal ones.

The objectives of this work were 1) To estimate age at the beginning and the peak of the growth spurt; 2) To estimate growth rate at the beginning and the peak of the growth spurt; 3) To estimate height at the beginning, at the peak of the growth spurt and the final adult height; and 4) To describe the differential patterns between the sexes.

Subjects and Method

A cross-sectional study was carried out with a population of 30,207 subjects aged from 2 to 18 years (15,405 girls and 14,802 boys) belonging to a prepaid private comprehensive medical care plan, which is only and exclusively seen at the Private University Hospital of Córdoba, Argentina. 80 subjects (40 boys and 40 girls) were randomly selected for each age group from 2 to 18 years, inviting 1,280 subjects to participate in the study.

Height data were collected prospectively. Healthy children and adolescents aged between 2 and 18 were included. Children and adolescents with birth weight < 2500 g, amputations, inability to move, chronic diseases, congenital or genetic disorders, or medication use that may affect or have affected growth were excluded. The participants were measured at the Private University Hospital of Córdoba (Argentina) between January 1, 2015, and December 31, 2016.

We obtained informed consent from parents or caregivers and informed assent from the children and adolescents. This study was approved by the Institutional Ethics Committee of our hospital. Four researchers collected the anthropometric data according to national guidelines[6-9]. Measurement error was controlled by intra- and inter-observer agreement test as previously described[10]. The height was measured using mechanical stadiometers, Seca 216 (Hamburg, Germany). Heights were recorded to the last full mm. In addition, the parents or caregivers answered a questionnaire on demographic and medical history.

Using the Kolmogorov-Smirnov test, normal continuous data were tested and reported as mean ± standard deviation, and the discrete ones were reported in absolute and relative frequencies with 95% confidence intervals.

We developed sex-adjusted percentile curves for height through the LMS[11] model using the GAMLSS (Generalized Additive Models for Location Scale and Shape) with the R package. This method uses a semi-parametric maximum probability to estimate smoothed growth curves that can be summarized as median (M), Generalized Variation Coefficient (S), and Box-Cox power for the bias (L) while representing kurtosis (T)[12]. Locally weighted *splines*, defined as a distinguishable curve delimited in portions by polynomials, were applied to adjust the curves for age to obtain objective adjustment functions that were used to calculate the 3rd, 50th, and 97th percentiles.

We carried out the external validation by comparing the values from our data with national reference values for children aged 2 to 18[9].

According to Rosique Gracia et al, the PB1 model fits for the study of growth in the adolescent period and has been used to describe the average height growth of longitudinal and transversal samples. The distance curve that describes the PB1 is divided into five parameters, s0, s1, and . The parameter h1 represents the upper asymptote (adult height) if cases are modeled, or the adult height at the 50th percentile if samples are modeled. It is the only parameter with biological interpretation since the rest are shape parameters and are only used to construct the function. Approximately, is related to the height at the decreasing slope of the growth spurt peak, the parameters s0 and s1 are related to the average increments during the growth spurt describing the shape of the peak, and the parameter is related to the age of . However, the first model's parameter is useful to obtain some data of interest, such as age and height at the beginning and the peak of the growth spurt.

The application of PB1 to transversal data produces percentile curves very similar to those derived from longitudinal sampling, except for the description of variance in adolescence and the expected flattening effect of the velocity curve. Therefore, it is more accurate to use the term "pseudo-velocity curve" in transversal studies, where adult height and age at the peak of the growth spurt are the population parameters that are extracted with less bias compared with longitudinal studies[8].

The PB1 model was used to estimate the following mathematical parameters: (adult height in cm), (height at age θ in cm), s_θ and s_1 (mean, prepubertal and pubertal increment constants in cm/year), and θ (age at the decreasing slope of the growth spurt peak in cm). The parameters were estimated based on the least squares. The respective values were generated by applying the PB1 model as follows:

The first model derivative (dy/dt) was used to establish the following biological parameters: T_1 (age in years at the beginning of growth spurt), V_1 (speed at the beginning of growth spurt in cm/year), T_2 (age in years at the peak of the growth spurt), and V_2 (speed at the peak of the growth spurt in cm/year)[6]. The data were analyzed with the R software version 3.5.1.

Results

Of the 1,280 subjects invited to participate in the study, 1,025 applied for eligibility. After the evaluation, 164 were excluded. The sample consisted of 861 subjects, 484 girls (56.2% CI 95% 52.8 to 59.5) with a mean height of 138.1 ± 20.3 cm, and 377 boys (43.8% CI 95% 40.4 to 47.2) with a mean height of 138.3 ± 24.5 cm. The sample was divided into 16 one-year strata from age 2 to 18 years for each sex. The decimal age range for girls was 2.375 to 18.923 years and for boys 2.013 to 18.948 years.

The percentiles calculated for height using the age- and sex-specific LMS parameters we generated from our data were compared with the 3rd, 50th, and 97th percentiles of the national reference for children aged 2 to 18. The differences were calculated using the national reference value as a minimum[6]. For both sexes, the data were reasonably adjusted with a mean relative difference of less than 1%. Both curves show practically the same height at 18 years in both sexes (Tables 1 and 2).

Figure 1 shows the height distance curves with the data observed in our sample and those estimated by the PB1 model for boys and girls as follow: estimated adult height (h_1) of 173.7 and 160.0 cm, estimated mean height at the peak of the growth spurt (h_θ) of 160.6 and 146.0 cm, and estimated age at the peak of the growth spurt (θ) of 13.6 and 11.0 years, respectively.

Figure 2 shows the height velocity curves for the data observed in the sample and those estimated by the PB1 model for boys and girls, respectively, as follow: age at the start of the growth spurt (T_1) 8.9 and 6.4 years; age at the peak of the growth spurt (T_2) 12.6 and 10.6 years; speed at the beginning of the growth spurt (V_1) 5.25 and 5.28 cm/year; and speed at peak of the growth spurt in cm/year (V_2) 6.40 cm/year and 6.44 cm/year.

Figure 3 shows the differences observed between boys and girls in the mathematical and biological parameters. Boys compared to girls had a final height 8.6% higher, an age at the peak of the growth spurt 2 years older, and a slightly lower average growth rate both prepubertal and pubertal.

Discussion

We are presenting, for the first time, a reference for assessing the age of onset and peak of the growth spurt along with the extent and speed of growth expected at these points using data derived from a cross-sectional sample of a present-day Cordovan population made up of healthy children and adolescents, whose curve fits very well with the national standard[9] using the PB1 model.

When comparing our results with the only existing cross-sectional study that used the PB1 model in a similar population[8], we found that the final height (h1) is smaller in our sample (173.7 cm vs 176.2 for boys and 160.0 vs 163.5 for girls), according to the expected inter-population variation[13]. However, the age at the peak of the growth spurt (θ) is very similar in both populations for boys (13.6 vs 13.7) and girls (11.04 vs 11.02).

Compared with the data of the current national reference created five decades ago[9], the height at 18 years of age observed in our sample was 1 cm higher in men and 0.7 cm lower in women. These results coincide with the available evidence that height has not changed in Argentina in the last decades[14,15].

Compared to data on the pubertal development of Argentinean boys and girls published in 1976[16], the subjects in this study presented an age at the beginning of the growth spurt (T1), related to the beginning of puberty, 2.2 years younger in boys (8.9 vs 11.1) and 4.4 years younger in girls (6.4 vs 10.8). This probably reflects the trend of earlier pubertal initiation also observed in other countries[17].

The decrease observed in the final height of women may also be related to the younger age of menarche[18], but this observation should be carefully considered un-

Table 1. Absolute (cm) and relative (%) differences (Δ) between our sample (CBA) and the national reference (SAP) for height percentiles (p) 3, 50 and 97

Boys	Age	N	CBA p3	CBA p50	CBA p97	SAP p3	SAP p50	SAP p97	Δ p3 cm	Δ p3 %	Δ p50 cm	Δ p50 %	Δ p97 cm	Δ p97 %
	2	26	79.7	86.6	93.6	82.0	87.8	93.5	2.4	1.3	1.2	1.2	0.0	1.1
	3	24	87.3	95.0	102.7	89.3	96.4	103.5	2.0	1.1	1.4	1.1	0.9	1.0
	4	25	94.5	102.9	111.2	94.6	102.6	110.6	0.0	1.1	-0.3	1.0	-0.6	0.9
	5	22	101.0	110.0	118.9	99.5	107.9	116.4	-1.6	1.0	-2.0	0.9	-2.5	0.8
	6	25	106.8	116.3	125.8	105.2	114.2	123.1	-1.6	0.9	-2.2	0.9	-2.7	0.8
	7	21	112.2	122.1	132.1	110.7	120.2	129.7	-1.4	0.9	-1.9	0.8	-2.4	0.8
	8	22	117.4	127.8	138.2	115.8	125.9	136.1	-1.6	0.9	-1.9	0.8	-2.2	0.7
	9	20	122.2	133.0	143.8	120.2	131.1	141.9	-2.0	0.8	-1.9	0.8	-1.9	0.7
	10	21	126.9	138.0	149.2	124.0	135.8	147.5	-2.8	0.8	-2.3	0.7	-1.7	0.7
	11	20	132.2	143.7	155.2	127.5	140.3	153.0	-4.7	0.8	-3.4	0.7	-2.2	0.6
	12	22	138.2	150.1	161.9	131.3	145.4	159.4	-7.0	0.7	-4.7	0.7	-2.5	0.6
	13	20	144.4	156.6	168.8	136.1	151.5	167.0	-8.3	0.7	-5.1	0.6	-1.8	0.6
	14	21	150.0	162.4	174.8	142.5	158.4	174.3	-7.5	0.7	-4.0	0.6	-0.5	0.6
	15	22	154.6	167.1	179.6	149.2	164.6	180.0	-5.4	0.6	-2.5	0.6	0.4	0.6
	16	23	157.9	170.3	182.8	154.6	169.1	183.6	-3.2	0.6	-1.2	0.6	0.8	0.5
	17	21	159.7	172.0	184.3	158.1	171.7	185.3	-1.6	0.6	-0.3	0.6	1.0	0.5
	18	22	160.9	173.0	185.1	159.7	172.7	185.7	-1.2	0.6	-0.2	0.6	0.7	0.5

Table 2. Absolute (cm) and relative (%) differences (Δ) between our sample (CBA) and the national reference (SAP) for height percentiles (p) 3, 50 and 97

Girls	Age	n	CBA p3	CBA p50	CBA p97	SAP p3	SAP p50	SAP p97	Δ p3 cm	Δ p3 %	Δ p50 cm	Δ p50 %	Δ p97 cm	Δ p97 %
	2	30	79.1	86.1	93.2	80.3	86.4	92.4	1.2	1.3	0.2	1.2	-0.8	1.1
	3	31	86.0	93.6	101.3	87.8	95.0	102.3	1.8	1.2	1.4	1.1	1.0	1.0
	4	28	92.8	101.0	109.3	92.9	101.2	109.5	0.2	1.1	0.2	1.0	0.2	0.9
	5	29	99.2	108.0	116.9	97.7	106.7	115.7	-1.5	1.0	-1.3	0.9	-1.2	0.9
	6	31	105.3	114.7	124.0	103.4	113.0	122.6	-2.0	0.9	-1.7	0.9	-1.5	0.8
	7	29	111.2	121.1	130.9	108.6	118.8	129.0	-2.6	0.9	-2.3	0.8	-2.0	0.8
	8	27	117.0	127.4	137.7	113.2	124.1	135.0	-3.8	0.9	-3.3	0.8	-2.7	0.7
	9	28	122.9	133.7	144.6	117.3	129.2	141.1	-5.6	0.8	-4.5	0.7	-3.5	0.7
	10	29	128.7	140.0	151.3	121.4	134.6	147.7	-7.3	0.8	-5.4	0.7	-3.6	0.7
	11	30	134.0	145.7	157.4	126.1	140.6	155.0	-7.9	0.7	-5.2	0.7	-2.4	0.6
	12	29	138.5	150.5	162.5	132.1	147.0	161.9	-6.4	0.7	-3.5	0.7	-0.5	0.6
	13	28	142.1	154.2	166.3	138.8	152.9	167.0	-3.2	0.7	-1.3	0.6	0.7	0.6
	14	27	144.6	156.8	169.0	144.3	157.2	170.0	-0.3	0.7	0.4	0.6	1.0	0.6
	15	28	146.1	158.3	170.5	147.6	159.6	171.6	1.4	0.7	1.3	0.6	1.1	0.6
	16	29	147.0	159.0	171.1	149.0	160.5	172.1	2.0	0.7	1.5	0.6	1.0	0.6
	17	27	147.4	159.4	171.3	149.3	160.7	172.2	1.9	0.7	1.4	0.6	0.9	0.6
	18	24	147.8	159.6	171.4	149.3	160.7	172.2	1.5	0.7	1.1	0.6	0.8	0.6

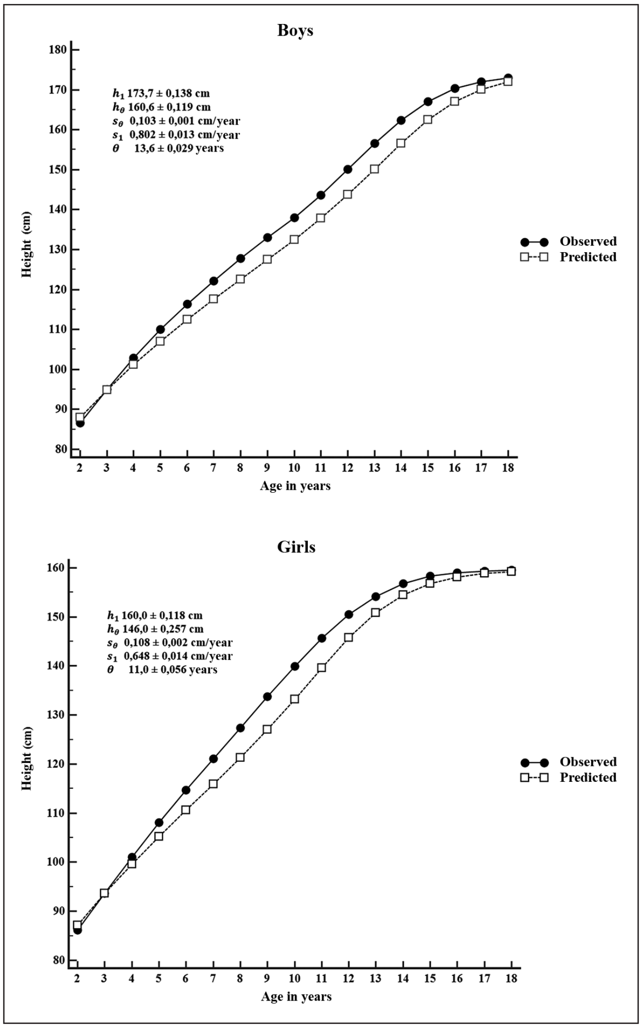

Figure 1. Distance curves for height with observed (Observed) data of our sample and estimated (Estimated) data by the Preece-Baines model 1 for boys (top) and girls (bottom). SEE = standard error of the estimate, *h1* = mean final height, h_θ = mean height at peak height velocity θ = age at of peak height velocity.

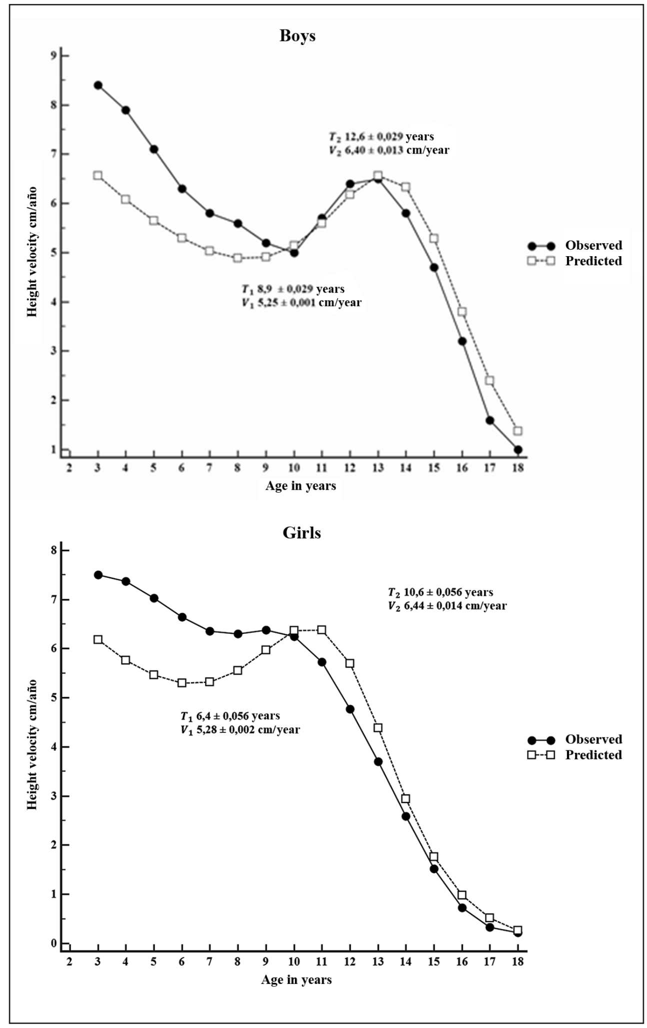

Figure 2. Velocity curves for height with observed (Observed) data of our sample and estimated (Estimated) data by the Preece-Baines model 1 for boys (top) and girls (bottom). SEE = standard error of the estimate. T1 = age at the beginning of the growth spurt, T2 = age at the peak of the growth spurt, V1 = growth velocity at the beginning of the growth spurt and V2 = growth velocity at the peak of the growth spurt.

til it is confirmed or refuted by a prospective longitudinal study that specifically investigates the influence of the age of menarche on the final adult height in our sphere. Growth occurred at similar rates in both sexes, but for longer in boys, explaining their higher final height. In American boys, the peak speed of growth spurt is 9.5 cm/year, while in girls it is 8.3 cm/year[19].

The different peak velocities of the growth spurt (V_2) between boys and girls have been associated with the increased testosterone-dependent bone growth that occurs in boys during puberty[20]. Unfortunately, there are no longitudinal data from Argentinean children that allow a comparison on this matter; however, the results of our cross-sectional study show a much lower speed at the peak of the growth spurt (V2) than those reported in an American longitudinal study[19]. In addition, no apparent difference is observed between boys and girls, although it is very similar to those reported by the Spanish cross-sectional study that used the PB1 model (6.1 cm/year for boys and 5.8 cm/year for girls)[8]. Quite possibly the PB1 model presents a lower estimate of the speed at the peak of the growth spurt compared with the models used in longitudinal studies, due to the flattening effect of the speed curve, although the values are within the ranges established by Tanner et al of 6.1 to 12.3 cm/year for boys and 6.2 to 10.3 cm/year for girls[21,22].

Regarding the differences in the speed of the peak of growth spurt between boys and girls, there is currently a growing number of researches carried out on twins, which

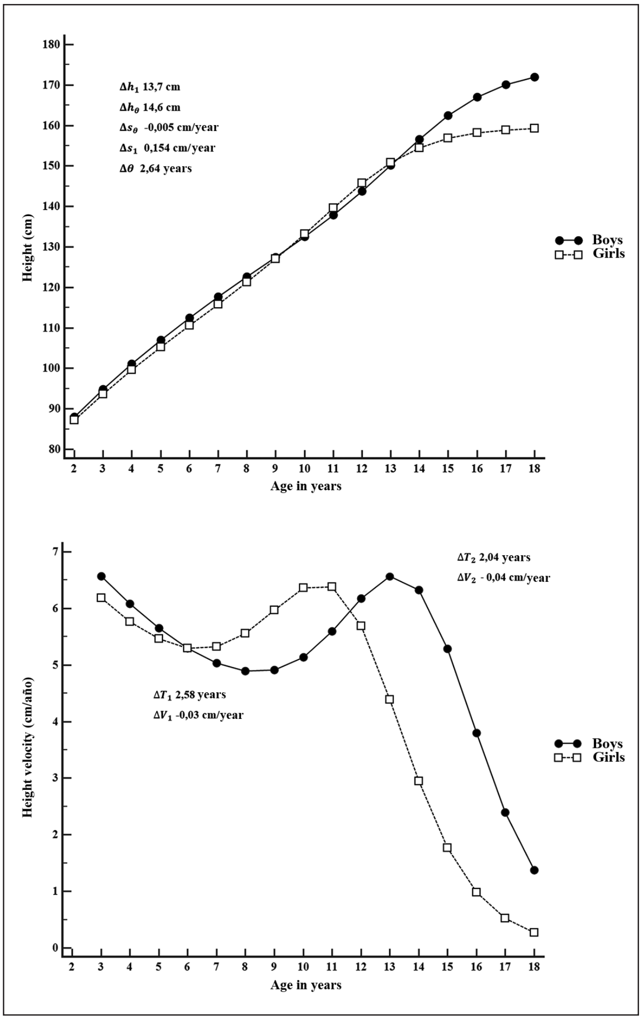

Figure 3. Difference curves (Δ) of the mathematical parameters: h_1 (adult height), h_θ (height at the age of the growth spurt peak), s_1 and s_θ (constants of mean increments, pubertal and prepubertal) and θ (age at the decreasing slope of the growth spurt peak) (top) and the biological parameters: T_1 (age at the beginning of the growth spurt), V_1 (velocity at the beginning of the growth spurt), T_2 (age at the growth spurt peak) and V_2 (velocity at the growth spurt peak) between boys and girls.

show that both sexes grow at the same speed if this is adjusted to pubertal maturation, and not to age, attributing the higher final height in males to the longer duration of both pre-pubertal and intrapubertal growth and not to a faster speed of growth. This fact is probably better reflected by the PB1 model than by the models used in the longitudinal studies[23-25].

This work is mainly limited by its transversal nature, so it should be considered as a provisional estimate until having definitive data from longitudinal studies. While considering the need for national longitudinal data, the parameters presented here come from a thorough analysis that has provided acceptable adjustments according to the estimated standard error values with those observed and has adequately controlled for potential biases in determining age and speed at the start and peak of the growth spurt but may have underestimated age at the beginning of the growth spurt, equivalent to the age of minimum speed of height in longitudinal studies.

The 2.5-year difference for the age at the beginning of the growth spurt between girls and boys found in this work is within the expected range. We believe that we have solved this problem by including children from all ages ranging from 2 to 18 years old with representative sample sizes in each stratum as proposed by Zemel and Johnston in their work on validation and interpretation of the PB1 model. These authors propose that the PB1 method can be successfully applied to cross-sectional growth data to make conclusions about both the timing of the peak of accelerated growth and the duration of this growth period in the adolescent.

The data for each cross-sectional sample was divided by sex and the mean height at each age was calculated and analyzed using the PB1 model. Thus, deductions about longitudinal growth processes, such as the moment of the adolescent's growth peak, obtained from cross-sectional data, could be tested with truly longitudinal records. Among randomly selected cross-sectional samples and longitudinal records for the same children, the comparisons of these authors revealed some differences between the two approaches. When using the PB1 model, it should be bear in mind that the mean velocity curve of the mathematical model is wider and flatter than the one of any single individual, so it should be used only to make population inferences, not individual ones.

The speed at peak of the growth spurt was lower than that determined longitudinally, but most of the other parameters examined, especially age at peak of the growth spurt, matches the information of cross-sectional data. However, the age at the peak of the growth spurt, particularly in girls, is significantly younger than that determined by longitudinal data compared with our study's findings, which is an important limitation of the method. Another relevant element to consider is that when this technique is used to compare populations, the variability that occurs within a population and among selected samples of the same population must be considered before reaching definitive conclusions[26].

In conclusion, the PB1 model allowed us to satisfactorily estimate the age at the beginning and the peak of the growth spurt, the growth rate at those points, and the expected final adult height in our sample, although these data should be considered provisional until confirmed with definitive data from longitudinal studies.

Ethical Responsibilities

Human Beings and animals protection: Disclosure the authors state that the procedures were followed according to the Declaration of Helsinki and the World Medical Association regarding human experimentation developed for the medical community.

Data confidentiality: The authors state that they have followed the protocols of their Center and Local regulations on the publication of patient data.

Rights to privacy and informed consent: The authors have obtained the informed consent of the patients and/or subjects referred to in the article. This document is in the possession of the correspondence author.

Conflicts of Interest

Authors declare no conflict of interest regarding the present study.

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