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Equations predicting maturity status: Validation in a cross-sectional sample to assess physical growth and body adiposity in Chilean children and adolescents☆

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Abstract
Objective: To validate regression equations that predict the state of maturity (MS) to evaluate the physical growth and body fatness of Chilean children and adolescents.
Material and methods: A transversal study was carried out in 8094 school children between 6.0 and 18.9 years old. Weight, standing height, sitting height, and waist circumference (WC) were evaluated. Peak growth rate (PVC) was estimated by the mathematical model 1 of Preece-Baines (MPB). Mirwald's equations (based on age, weight, standing height, sitting height, and leg length) and Moore's equations (based on age, weight, and standing height) were used to estimate MS. The body mass index (BMI) was calculated.
Results: The BMP showed that the PVC in men was 10.33 ± 0.29 years and in women was 12.81 ± 0.27 years. Using Mirwald's equation, men reached MS at 14.09 ± 0.8 APVC and women at 11.6 ± 0.9 APVC, while using Moore's equation, men reached 13.7 ± 0.6 APVC and women at 12.1 ± 0.6 APVC. There were significant differences between MPB with Mirwald, MPB with Morre, and between Mirwald and Moore ($p < 0.001$). Explanation values by MS category were

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Mirwald's equation [men (early $R^2 = 0.81$, mean $R^2 = 0.69$ and late $R^2 = 0.09$) and women (early $R^2 = 0.83$, mean $R^2 = 0.83$ and late $R^2 = 0.77$)], Moore's equation [men (early $R^2 = 0.93$, mean $R^2 = 0.70$ and late $R^2 = 0.79$) and women (early $R^2 = 0.89$, mean $R^2 = 0.89$ and late $R^2 = 0.83$)]. Percentiles were created for weight, height, CC and BMI.
Conclusion: It was verified that Moore's and Mirwald's equations differ with the mathematical model MPB in both sexes. However, Moore's equation could be useful for the evaluation of MS in Chilean children and adolescents.
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PALABRAS CLAVE
Estado de madurez;
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Adolescentes

Ecuaciones que predicen el estado de madurez: Validación en una muestra transversal para evaluar el crecimiento físico y adiposidad corporal en niños y adolescentes chilenos

Resumen
Objetivo: Validar ecuaciones de regresión que predicen el estado de madurez (EM) para evaluar el crecimiento físico y adiposidad corporal de niños y adolescentes chilenos.
Material y métodos: Se efectuó un estudio transversal en 8.094 escolares de entre 6,0 y 18,9 años. Se evaluó el peso, la estatura de pie, la estatura sentada y la circunferencia de cintura (CC). El pico de velocidad de crecimiento (PVC) se estimó por el modelo matemático 1 de Preece-Baines (MPB). Para estimar el EM, se utilizaron las ecuaciones de Mirwald (basadas en edad, peso, estatura de pie, estatura sentada y longitud de piernas) y las ecuaciones de Moore (basadas en edad, peso y estatura de pie). Se calculó el índice de masa corporal (IMC).
Resultados: El MPB evidenció que el PVC en hombres fue de $10{,}33 \pm 0{,}29$ años y en mujeres fue a los $12{,}81 \pm 0{,}27$ años. Por medio de la ecuación de Mirwald, los hombres alcanzaron el EM a los $14{,}09 \pm 0{,}8$ APVC y las mujeres los $11{,}6 \pm 0{,}9$ APVC, mientras que, por la ecuación de Moore, los hombres alcanzaron a los $13{,}7 \pm 0{,}6$ APVC y las mujeres a los $12{,}1 \pm 0{,}6$ APVC. Hubo diferencias significativas entre el MPB con Mirwald, MPB con Moore y entre Mirwald con Moore ($p < 0{,}001$). Los valores de explicación por categoría de EM fueron: ecuación de Mirwald [hombres (precoz $R^2 = 0{,}81$, promedio $R^2 = 0{,}69$ y tardío $R^2 = 0{,}09$) y mujeres (precoz $R^2 = 0{,}83$, promedio $R^2 = 0{,}83$ y tardío $R^2 = 0{,}77$)], ecuación de Moore [hombres (precoz $R^2 = 0{,}93$, promedio $R^2 = 0{,}70$ y tardío $R^2 = 0{,}79$) y mujeres (precoz $R^2 = 0{,}89$, promedio $R^2 = 0{,}89$ y tardío $R^2 = 0{,}83$)]. Se crearon percentiles para peso, estatura, CC e IMC.
Conclusión: Se verificó que las ecuaciones de Moore y Mirwald difieren con el modelo matemático MPB en ambos sexos, aunque, la ecuación de Moore podría ser útil para la evaluación del EM en niños y adolescentes chilenos.
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Introduction

Physical growth is considered to be a dynamic, complicated and long process that continues throughout infancy, childhood and adolescence,[1] while maturation is a process of major physiological changes that manifest most intensely during adolescence.

Both are complex physiological processes that are controlled and affected by hormonal, environmental, and genetic factors,[2] and they occur simultaneously.[3]

Infancy, childhood and adolescence are obviously very interesting stages in research in the health sciences; of particular interest are evaluation and follow-up of physical growth, nutritional status, changes in maturity stage (MS) and lifestyle, among other matters.

During these stages, opportunities arise for the individual to express his or her genetic potential; these opportunities may in turn be modified by the individual's environment. Studies of these factors are important in paediatric research, since they involve constant monitoring, diagnosis and follow-up in growth and biological maturation processes with the goal of identifying children at nutritional risk.[4] Some recent studies in this regard have found early puberty to be associated with higher risks of overweight and obesity.[5,6] Hence, there is an urgent need to include MS indicators in the evaluation of growth and body composition, as this may provide a more accurate means of adjustment in the evaluation of nutritional status during growth and development.

In general, methods of MS evaluation (bone age and secondary sex characteristics, age of menarche and percentage of adult height) are often impractical and considered invasive.[7–9] This is a major drawback for epidemiology research and prevents their use in and application to large populations.

As such, two non-invasive techniques based on somatic indicators that enable prediction of MS in children and adolescents have been proposed in recent years. The first, from Mirwald et al.,[10] is based on variables of age, weight, height, sitting height and leg length (height minus sitting height). The second, from Moore et al.,[11] uses chronological age, weight and height.

Both techniques have been developed from the same database and have been widely used in studies having to do with monitoring of and participation in programmes of physical activity,[12] follow-up of physical growth,[13] strength training in athletes,[14] and identification of talent in sport,[15] among other studies.

Kozieł and Malina [16] recently validated both techniques in Polish children and adolescents using a longitudinal criterion, noting that the Moore et al.[11] equations, despite having significant limitations, are useful in children and adolescents. However, to the best of our knowledge, in South America in general and Chile in particular, no studies have compared and validated these equations according to a cross-sectional and/or longitudinal design. Identifying the technique best suited to the Chilean population could aid in interpreting physical growth and body fat parameters in paediatric populations.

Thus, based on these premises, this study had the following objective: to validate the regression equations that predict MS in a sample of Chilean children and adolescents (the Mirwald et al.[10] and Moore et al.[11] equations), using Preece and Baines' mathematical model 1[17] for cross-sectional samples, or Preece and Baines' model (PBM), as a criterion method. This model enables estimation of growth velocity, especially in large samples of children and adolescents.[18]

This information may help to determine nutritional risk in children who are advanced in terms of maturity,[6] since puberty intensity and duration are specific to each individual and may vary considerably across individuals.[13]

Methods

Study type and sample

A cross-sectional (comparative) study was conducted in children and adolescents from the Maule region of Chile. The sample population consisted of 31,696 students with ages ranging from 6.0 to 18.9 years. The students were from four provinces in the Maule region (Cauquenes, Curicó, Linares and Talca). They attended 12 municipal primary and secondary schools. Probabilistic (random) sampling was used to calculate sample size, yielding a sample of 8094 subjects (4260 [13.43%] males and 3834 [12.0%] females) with a 95% CI.

The students' parents and/or guardians signed the informed consent form, and each student signed the informed assent form. The study was conducted in accordance with the Declaration of Helsinki for human beings and the suggestions of the independent ethics committee of the Universidad Autónoma de Chile [Autonomous University of Chile] (protocol no. 238/2013). Students who voluntarily agreed to participate and completed the anthropometric evaluations were included. Those who were not in attendance on the day of the evaluation or did not complete the anthropometric evaluations were excluded.

Techniques and procedures

Anthropometric variables were measured at the schools' facilities during school hours (8:00 AM–12:30 PM and 2:30 PM–6:00 PM) between Monday and Friday. This was done in 2015 and 2016. For purposes of evaluation, a team of six experienced evaluators trained in anthropometric evaluations was formed. All variables were evaluated twice, and rates of intra-evaluator and inter-evaluator errors in measurement technique (EMT) were 1%–2%.

Anthropometric measurements were evaluated as recommended by Ross and Marfell-Jones.[19] Measurements were taken with the students wearing minimal clothing: a light shirt, shorts and no shoes. Body weight (kg) was determined using electronic scales (Tanita, United Kingdom) capable of weighing 0–150 kg with accuracy within 100 g. Standing height was determined using a portable stadiometer (Seca GmbH & Co. KG, Hamburg, Germany) with accuracy within 0.1 mm, according to the Frankfurt plane. Sitting height was measured on a wooden bench (a flat box with a height of 50 cm) with a stadiometer (SECA, Hamburg, Germany) with accuracy within 0.1 mm. Waist circumference (WC) (cm) was measured at the midpoint between the lower ribs and the upper part of the iliac crest with a metal anthropometric tape measure (Seca brand), graduated in millimetres with accuracy within 0.1 cm. Body mass index (BMI) was calculated using the following formula: BMI = weight (kg)/height^2 (m).

The criterion method for evaluating peak height velocity (PHV) in children and adolescents was the PBM.[17] This model is employed in cross-sectional and longitudinal studies of growth[20] and used to infer growth acceleration and determine the age at which adult height is reached. This exponential logistic model multiplied was:

$$\text{Height} = \frac{2\,(h_1 - h_\theta)}{e^{s0}\,(t-\theta) + e^{s1}\,(t-\theta)} \tag{1}$$

This model represents five parameters: h_1 represents the upper asymptote (adult height), $h\theta$ is related to height, S0 and S_1 are related to mean increases in growth (shape of the peak), and the θ parameter is related to $h\theta$ age.

The MS of the students studied was determined through years of peak height velocity (PHV). It was calculated using the regression equation proposed by Mirwald et al.[10] This method includes standing height, sitting height, leg length (standing height minus sitting height) and their interactions:

Females: Maturity stage (years) = −9.376 + (0.0001882 × [leg length × sitting height]) + (0.0022 × [age × leg length]) + (0.005841 × [age × standing height]) − (0.002658 × [age × weight]) + (0.07693 × [weight-to-height ratio × 100]).

Males: Maturity stage (years) = −9.236 + (0.0002708 × [leg length × sitting height]) + (−0.001663 × [age × leg length])

+ (0.007216 × [age × standing height]) + (0.02292 × [weight-to-height ratio × 100]).

The equations proposed by Moore et al.[11] use age and standing height for both sexes:

Females: Maturity stage (years) = −7.709133 + (0.0042232 × [age × height]).

Males: Maturity stage (years) = −7.999994 + (0.0036124 × [age × height]).

To classify MS, the method suggested by Malina and Koziel was used,[16] with young people within −1 to +1 years of PHV classified as average, those under −1 years of PHV classified as early and those over +1 years of PHV classified as late.

Statistics

The normal distribution of the data was verified using the Kolmogorov−Smirnov (K−S) test. Descriptive statistics (mean, standard deviation, range, frequency and percentage) were calculated. The differences between the two sexes were determined using the independent samples t test. Comparisons between the PBM and the regression equations were made using the related samples test. Relationships between variables were verified using Pearson's r, adjusted R^2 and standard error of estimate (SEE). In all cases, $p < 0.05$ was considered significant. Calculations were performed in Excel spreadsheets and SPSS 18.0. The PBM was calculated and the PHV graph prepared in the R software environment.

Results

Table 1 shows the comparisons of the physical growth and body fat variables, aligned by MS for both equations. For the Mirwald equation, MS ranged in males from −6 to +4 years of PHV and in females from −6 to +9 years of PHV. For the Moore equation, MS values ranged from −5 to +5 years of PHV in males and from −5 to +6 years of PHV in females.

Significant differences were seen in males; the MS values calculated using the Mirwald equation were higher for age, weight and height compared to the Moore equation on all levels. However, in WC, differences were seen from −5 to 0 years of PHV, and from +2 to +4 years of PHV, and in BMI, differences were seen from 0 to +5 years of PHV. There were no differences in BMI from −6 to −1 years of PHV ($p > 0.05$).

In females, there were no significant differences in age, weight or height from −5 to −1 years of PHV; however, differences started to appear from 0 to +6 years of PHV in the physical growth variables (age, weight and height) ($p < 0.05$), while in the body fat variables (WC and BMI), differences were found from +1 to +4 years of PHV, with the Moore equation showing higher values than the Mirwald equation. In addition, there were no significant differences in the body fat variables from −5 to 0 years of PHV and +5 and +6 years of PHV ($p > 0.05$).

Fig. 1 shows the curve of PHV by chronological age determined by the PBM. Note that PHV was determined at 10.33 ± 0.29 years of age in females and at 12.81 ± 0.27 years of age in males. Growth velocity was 6.90 ± 0.96 cm per year in females and 7.11 ± 1.47 cm per year in males.

Table 2 shows the comparisons between the PBM and the Mirwald and Moore equations for both sexes. The PBM differed significantly from both equations in both sexes ($p < 0.001$); in addition, there were differences between the Mirwald and Moore equations in both sexes ($p < 0.001$).

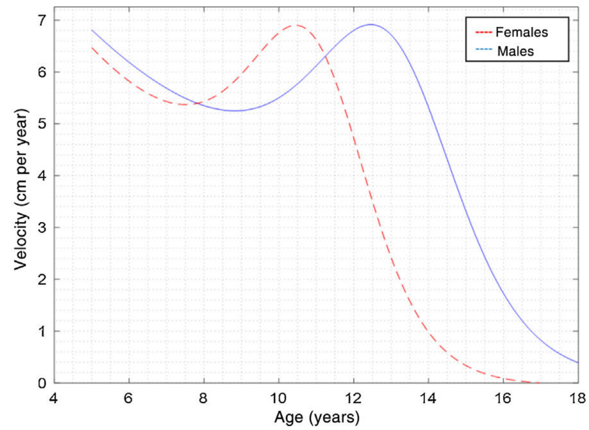

Figure 1 Peak height velocity (PHV) curves for both sexes determined by the PBM for the cross-sectional sample of Chilean children and adolescents.

Table 3 shows the MS categories according to the physical growth and body fat variables for both equations. Significant differences between the two equations were found in both sexes. In males, the Mirwald equation showed higher values for age, weight and height in the average and late categories ($p < 0.05$), while in the early category there were no significant differences ($p > 0.05$). In females, the Moore equation showed higher values for age, weight and height in the average and late categories; however, in the late category, there were no significant differences between the two equations ($p > 0.05$).

In the body fat variables (WC and BMI), in males, the Mirwald equation showed significantly higher values than the Moore equation in the average and late categories for WC and BMI ($p < 0.05$). There were no differences in the early category in both body fat indicators (WC and BMI) ($p > 0.05$). In females, the Moore equation showed higher values than the Mirwald equation in WC and BMI in the early and average categories ($p < 0.05$). However, in the late category, no significant differences were seen in either WC or in BMI ($p > 0.05$).

Relationships between chronological age and each MS category are shown in Figs. 2 and 3. Coefficient of determination values by MS category, using the Mirwald equation, were relatively low compared to the Moore equation in both sexes. Using the Mirwald equation, R^2 values ranged from 0.09 to 0.81 in males and from 0.57 to 0.83 in females. Using the Moore equation, said values ranged from 0.63 to 0.93 in males and from 0.71 to 0.98 in females.

Discussion

The results of the study demonstrated significant differences between the PBM and the Mirwald and Moore equations in both sexes. These findings indicate that both anthropometric equations for predicting MS in children and adolescents could not be applied to Chilean children and adolescents.

Indeed, years of PHV determined by the PBM reflected much earlier ages than the regression equations:

Table 1 Physical growth and body fat variables, aligned by chronological age and MS in children and adolescents of both sexes.

Ages (years)	Study (Chile)								Equation (Mirwald)											Equation (Moore)										
	n	Weight (kg)		StH (cm)		SiH (cm)		MS	n	Age (years)		Weight (kg)		StH (cm)		WC (cm)		BMI (kg/m^2)		n	Age (years)		Weight (kg)		StH (cm)		WC (cm)		BMI (kg/m^2)	
		X	SD	X	SD	X	SD			X	SD	X	SD	X	SD	X	SD	X	SD		X	SD	X	SD	X	SD	X	SD	X	SD
Males																														
6–6.9	117	27.3	8.9	120.7	6.1	64.7	6.1	−6.0	121	6.6	0.4	26.3	7.5	119.6	4.1	58.5	6.5	18.3	4.7											
7–7.9	101	30.3	6.9	127.1	6.5	67.9	5.7	−5.0	208	8.3	1.2	32.3	8.1	129.9	6.9	63.6	8.9	19.0	3.4	173	6.8	**0.5**	27.0	**6.8**	121.2	**4.7**	59.4	**6.5**	18.3	4.2
8–8.9	141	34.0	7.6	131.9	6.4	69.6	3.9	−4.0	395	10.0	1.2	39.1	9.0	139.3	8.5	66.5	10.1	20.0	3.4	231	8.5	**0.5**	33.6	**7.9**	131.3	**6.3**	65.0	**10.1**	19.4	3.9
9–9.9	206	36.9	7.7	137.0	8.0	71.6	3.7	−3.0	397	11.5	1.0	45.0	9.4	147.0	7.3	70.9	8.9	20.7	3.4	310	10.0	**0.5**	38.8	**7.8**	139.2	**6.0**	67.5	**10.6**	19.9	3.1
10–10.9	237	42.4	9.2	142.5	7.2	73.8	3.9	−2.0	420	12.7	0.8	50.1	9.0	154.1	6.5	72.0	8.7	21.0	3.3	334	11.4	**0.6**	44.9	**8.8**	146.2	**5.7**	70.2	**9.0**	20.9	3.2
11–11.9	257	47.8	10.8	149.5	8.2	77.0	6.0	−1.0	606	13.7	0.7	57.0	10.6	163.1	5.8	74.9	10.2	21.4	3.6	452	12.7	**0.7**	50.7	**10.4**	153.8	**7.3**	72.2	**9.5**	21.4	4.3
12–12.9	385	50.9	10.9	155.2	8.0	78.9	7.1	0.0	727	14.9	0.8	64.4	10.9	168.1	8.4	78.7	10.4	22.8	3.9	621	13.7	**0.6**	57.1	**10.7**	162.3	**5.7**	74.5	**9.7**	21.6	**3.7**
13–13.9	529	56.3	11.8	161.4	8.9	82.3	6.7	1.0	834	16.3	0.8	67.9	11.1	170.4	6.6	78.7	11.0	23.4	3.7	757	14.8	**0.5**	64.0	**11.3**	168.3	**5.0**	78.5	**10.7**	22.6	**3.8**
14–14.9	627	62.2	12.9	166.5	9.7	85.4	5.3	2.0	494	17.3	0.6	72.3	12.6	173.8	6.0	80.6	10.9	23.9	4.0	778	16.3	**0.7**	67.6	**11.4**	170.7	**5.7**	78.7	**11.4**	23.2	**3.7**
15–15.9	550	65.6	11.2	169.7	7.0	88.3	4.1	3.0	53	18.0	0.6	77.0	14.6	178.6	5.7	81.5	10.0	24.2	4.9	541	17.4	**0.5**	72.0	**12.6**	173.6	**5.4**	80.4	**10.3**	23.9	**3.8**
16–16.9	513	68.9	13.2	171.1	7.5	89.9	3.9	4.0	5	17.5	0.1	93.1	4.9	182.2	4.4	94.5	12.0	28.3	5.2	63	18.1	**0.5**	81.8	**10.8**	185.5	**5.0**	81.4	**8.8**	22.8	**3.4**
17–17.9	529	69.6	11.3	171.4	6.3	89.5	3.7																							
18–18.9	68	71.5	12.8	172.0	7.1	90.9	3.4																							
Females																														
6–6.9	120	27.1	6.6	120.6	8.4	64.8	8.0	−6.0	5	6.1	0.1	21.4	2.5	112.0	1.7	54.8	2.3	17.0	1.6											
7–7.9	145	30.6	8.2	127.5	8.4	67.7	5.0	−5.0	143	6.7	0.4	25.5	5.0	119.9	5.6	57.6	6.6	17.7	3.0	38	6.3	0.2	24.4	3.7	115.0	5.1	56.5	4.0	18.4	2.5
8–8.9	154	31.9	7.8	129.3	6.5	68.1	3.7	−4.0	151	7.8	0.6	28.7	4.6	125.7	4.1	60.8	6.2	18.1	2.4	211	7.2	0.5	27.2	5.1	123.0	4.8	59.5	6.8	17.9	2.8
9–9.9	220	38.7	9.2	139.2	7.5	72.3	5.2	−3.0	165	8.7	0.6	33.4	6.6	132.8	5.8	64.0	9.3	18.9	3.1	208	8.6	1.0	34.3	9.0	131.3	9.6	64.7	9.9	20.4	12.2
10–10.9	294	42.6	9.4	144.2	7.1	75.3	4.6	−2.0	192	9.7	0.7	38.2	7.6	138.5	5.7	66.0	11.5	19.9	3.4	257	9.8	0.5	38.5	7.4	139.0	5.8	66.4	10.5	19.8	3.1
11–11.9	263	46.9	9.0	149.7	7.3	77.9	5.5	−1.0	268	10.5	0.5	42.4	6.8	144.8	5.2	67.9	8.6	20.2	2.9	322	10.8	0.6	43.7	8.8	145.4	6.0	68.0	8.7	20.7	3.8
12–12.9	377	53.0	11.6	155.1	5.8	81.4	5.2	0.0	199	11.6	0.9	45.6	8.2	147.0	9.8	69.4	8.7	21.7	10.1	385	12.1	0.6	49.9	**10.3**	152.3	**5.6**	70.8	8.3	21.5	4.2
13–13.9	370	54.8	10.1	156.2	7.2	82.0	5.0	1.0	299	12.3	0.7	49.4	7.1	152.8	6.4	70.5	6.9	21.4	6.6	493	13.3	**0.6**	54.7	**9.6**	155.9	**5.0**	73.2	**8.8**	22.5	**3.7**
14–14.9	522	58.4	10.9	158.4	6.6	83.2	5.0	2.0	336	13.1	0.7	53.1	8.4	155.3	5.0	72.7	8.3	22.0	3.4	628	14.6	**0.6**	58.1	**10.1**	158.4	**5.0**	74.2	**9.1**	23.1	**3.8**
15–15.9	369	59.4	10.9	159.0	5.1	84.7	3.3	3.0	438	14.1	0.7	55.3	8.5	157.4	5.0	72.6	8.5	22.3	3.4	614	16.0	**0.7**	59.4	**11.0**	158.4	**6.0**	74.8	**10.2**	23.7	**4.2**
16–16.9	450	60.9	12.0	159.0	6.9	84.5	3.6	4.0	494	15.1	0.8	58.4	9.0	158.6	5.4	74.0	9.3	23.2	3.4	586	17.2	**0.5**	62.5	**12.2**	160.1	**4.7**	76.1	**9.5**	24.3	**4.1**
17–17.9	487	60.6	11.4	158.2	7.3	84.0	3.4	5.0	504	16.3	0.9	58.5	10.5	158.2	5.2	73.8	8.8	23.4	4.2	90	17.9	**0.5**	63.1	**9.1**	165.9	**4.5**	74.8	7.5	22.9	3.1
18–18.9	63	59.3	9.1	160.1	6.0	85.5	3.1	6.0	390	17.0	0.7	63.3	10.0	160.1	4.4	77.2	9.3	24.7	3.9	2	18.4	**0.8**	70.9	**0.4**	170.7	**7.4**	78.5	0.7	24.4	2.0
								7.0	189	17.4	0.6	69.3	9.9	163.5	4.7	80.3	9.0	26.0	4.4											
								8.0	56	17.5	0.7	84.7	13.6	166.3	4.4	88.3	11.8	30.7	5.3											
								9.0	5	18.1	1.1	83.0	15.7	169.7	4.7	82.3	4.5	28.7	3.8											

Bold indicates a significant difference in relation to the Mirwald according to maturity stage.
BMI: body mass index; MS: maturity stage; SD: standard deviation; SiH: sitting height; StH: standing height; WC: waist circumference; X: arithmetic mean.

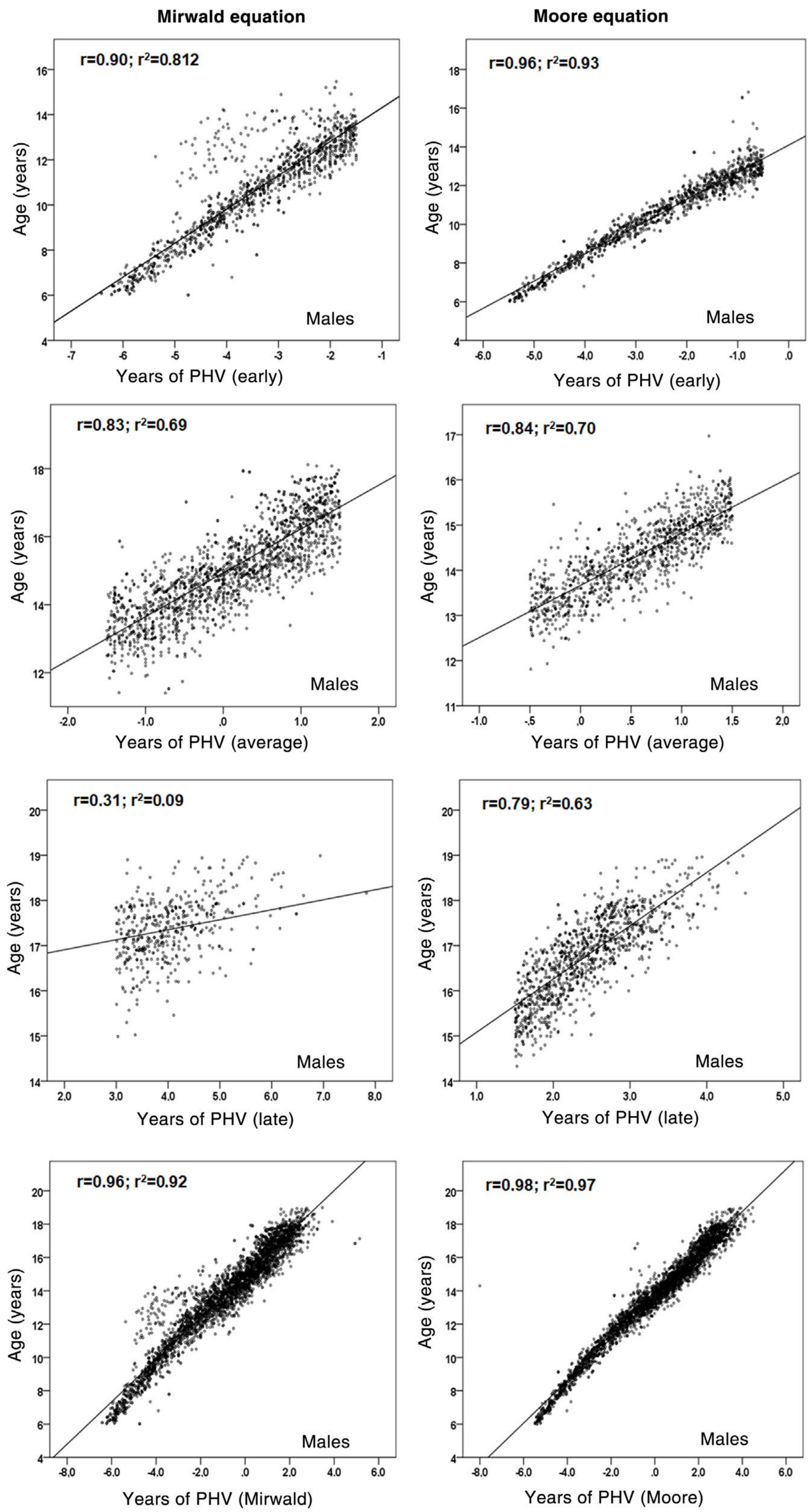

Figure 2 Relationship between chronological age and maturity stage categories (early, average and late) for both equations (Mirwald and Moore) in males.

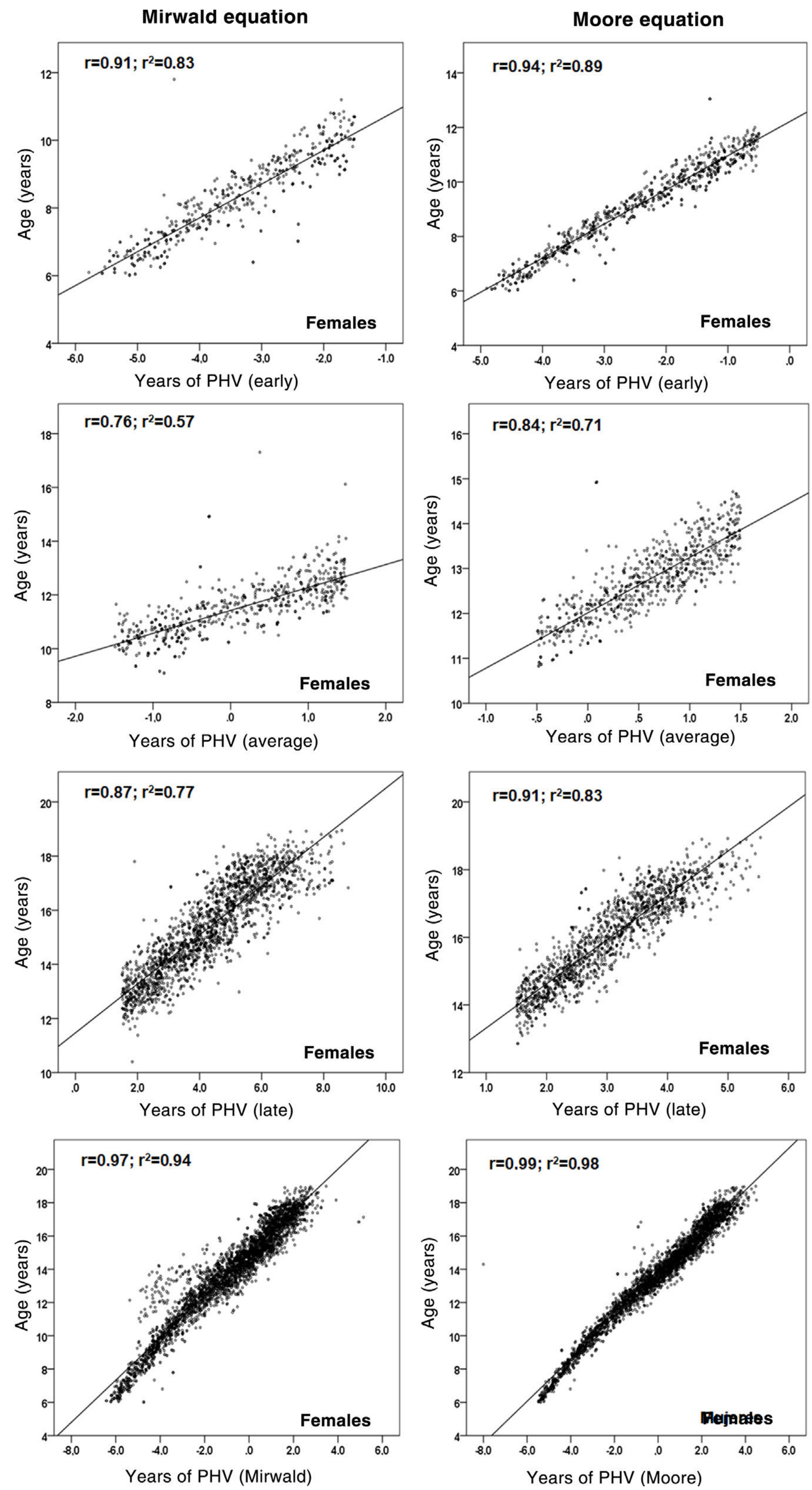

Figure 3 Relationship between chronological age and maturity stage categories (early, average and late) for both equations (Mirwald and Moore) in females.

Table 2 Comparison of mean peak height velocity (PHV) values in children and adolescents of both sexes.

Comparisons	Females		Males	
	Difference in means	p	Difference in means	p
PBM/Mirwald	1.27	0.001	1.28	0.001
PBM/Moore	1.68	0.001	0.89	0.001
Mirwald/Moore	−0.41	0.001	0.39	0.001

PBM: Preece and Baines' model.

Table 3 Comparison of physical growth and body fat variables, categorised by MS for both sexes and equations.

Equations		Age (years)		Weight (kg)		Height (cm)		WC (cm)		BMI (kg/m^2)	
	n	X	SD	X	SD	X	SD	X	SD	X	SD
Males											
Mirwald											
Early	1541	10.6	2.1	41.7	11.5	142.5	12.6	68.1	9.9	20.2	3.6
Average	2167	15.1	1.3*	63.7	11.7*	167.6	7.7*	77.6	10.7*	22.6	3.8*
Late	552	17.4	0.6*	72.9	13.0*	174.3	6.2*	80.9	10.9*	24.0	4.1*
Total	4260	13.8	3.0	56.9	16.7	159.4	16.1	74.6	11.6	21.9	4.0
Moore											
Early	1501	10.5	2.0	41.6	11.9	141.8	12.9	68.2	10.3	20.3	3.9
Average	1378	14.3	0.8	60.9	11.6	165.6	6.1	76.7	10.4	22.2	3.8
Late	1381	16.8	0.9	69.6	12.1	172.3	6.0	79.5	10.9	23.4	3.8
Total	4260	13.8	3.0	56.9	16.7	159.4	16.1	74.6	11.6	21.9	4.0
Females											
Mirwald											
Early	658	8.3	1.3*	31.9	7.9*	129.9	9.0	62.4	9.4*	18.7	3.1*
Average	767	11.5	1.0*	46.0	7.9*	148.5	7.9	69.3	8.1*	21.1	6.8*
Late	2409	15.4	1.6	59.4	11.2	158.7	5.5	74.9	9.5	23.6	4.1
Total	3834	13.4	3.1	52.0	14.6	151.7	12.6	71.6	10.3	22.2	5.0
Moore											
Early	1036	9.2	1.6	36.4	10.0	135.3	11.3	64.7	9.6	19.8	6.3
Average	878	12.7	0.8	52.6	10.2	154.3	5.6	72.1	8.7	22.1	4.0
Late	1920	16.0	1.3	60.1	11.2	159.3	5.5	75.0	9.5	23.7	4.0
Total	3834	13.4	3.2	52.0	14.6	151.7	12.6	71.6	10.3	22.2	5.0

BMI: body mass index; MS: maturity stage; SD: standard deviation; WC: waist circumference; X: arithmetic mean.
* Significant difference in relation to the Moore equation.

10.33 ± 0.29 years in females and 12.81 ± 0.27 years in males; therefore, there is a difference in upper means when predicting using the Mirwald and Moore equations (~0.89 to ~1,68 years).

In addition, years of PHV in this study determined by the PBM were verified to be similar to those reported in samples from cross-sectional studies from Peru[21] and Mexico,[22] with which this evidence confirms that girls generally exhibit earlier growth and reach their final size before their male counterparts.

The results also confirmed that there were significant differences between the two regression equations in both males and females. The Mirwald equation showed higher values in males (in the growth and body fat variables) in the average and late categories compared to the Moore equation; by contrast, in females, the Mirwald equation showed lower values (weight, height, WC and BMI) in the early and average categories compared to the Moore equation. There were no differences in males when classified with late maturity, while there were no differences in females when classified with early maturity.

As a result, after the differences between the two equations were verified, the relationship between chronological age and each MS category (early, average and late) was examined to verify the degree of association of each equation. The Moore equations in both sexes were found to reflect relatively higher values than the Mirwald equation in the three MS categories. This suggests that they could be applied to samples of Chilean children and adolescents, although both equations in their studies show similar powers of explanation (89% and 90%).

These results obtained in this study could be associated with a lower SEE in the Moore equation compared to the Mirwald equation, since previous studies had already warned of some limitations of the Mirwald equation,[10,23] especially in individuals further away from their years of PHV.[16,23]

In fact, the regressions observed in this study indicate that in the late MS category, the percentages of explanation in both sexes were lower with respect to the Moore equation, especially in males, confirming a lower power of explanation in young people with more advanced years of PHV, as seen in some studies.[10,24]

To date, the Mirwald equation has been widely used and applied in various populations around the world[13,24,25] and in Chile,[26,27] perhaps because it is older and has been more widely circulated since its publication; the equation proposed by Moore was published five years ago, and it may take longer to be circulated and gain recognition in the fields of health sciences and sport sciences.

In this regard, it should be noted that the SEE of the equations proposed to non-invasively determine MS and the number of predictors will be subject to further research in various sociocultural contexts, as there is a common interest in arriving at accurate and precise estimates, and consequently external validity, although on the other hand each population must develop its own equations[10] reflecting its own reality.

It must also be clarified that maturation is a biological process of progress towards maturity and varies across body systems.[16] It has two important dimensions: stage and timing. The former refers to the level of maturation at the time of observation, and the latter refers to the age at which specific maturation occurs.[3] The equations investigated in this study deal with years of PHV reached for a particular chronological age; however, maturity stage cannot be determined using the equations analysed. This is an important gap to be filled by further research.

Controlling for the effects of maturity and the substantial range in terms of rate and timing of growth in paediatric populations remains a challenge,[11] especially in the field of research, and offers new opportunities and prospects for professionals to continue to propose non-invasive, easy-to-use alternatives in health sciences and sport sciences.

In general, this study has various strengths related to its sample size and selection type, as well as the reliability of its anthropometric measurements, which showed EMT values of less than 2%. It is even the first large-scale study conducted in Chile to monitor MS. However, future studies should attend to other criteria for validation of regression equations to estimate MS, since this study was limited solely to validation through the PBM as longitudinal samples were not available. Future studies of Chilean children and adolescents should be longitudinal in nature; with them, new equations specific to regional populations could be proposed.

Conclusion

In conclusion, the Moore and Mirwald equations were confirmed to differ from the PBM in both sexes; however, the Moore equation could be useful for evaluating MS in Chilean children and adolescents, as its proposed equations showed a smaller error of estimate.

Conflicts of interest

The authors declare that they have no conflicts of interest.

References

1. Cossio-Bolaños M, Campos RG, Andruske CL, Viveros A, Luarte Rocha C, Olivares P, et al. Physical growth, biological age, and nutritional transitions of adolescents living at moderate altitudes in Peru. Int J Environ Res Public Health. 2015;12:12082–94, http://dx.doi.org/10.3390/ijerph121012082.
2. Wei C, Gregory JW. Physiology of normal growth. Paediatr Child Health. 2009;19:236–40, http://dx.doi.org/10.1016/j.paed.2009.02.007.
3. Malina RM. Assessment of biological maturation. In: Armstrong N, van Mechelen W, editors. Oxford textbook of children's exercise science and medicine. Oxford: University Press; 2017. p. 3–11.
4. Gomez-Campos R, Arruda M, Luarte-Rocha C, Urra Albornoz C, Almonacid Fierro A, Cossio-Bolaños M. Enfoque teórico del crecimiento físico de niños y adolescentes. Rev Esp Nutr Hum Diet. 2016;20:244–53, http://dx.doi.org/10.14306/renhyd.20.3.198.
5. Coelho-e-Silva MJ, Vaz Ronque ER, Cyrino ES, Fernandes RA, Valente-dos-Santos J, Machado-Rodrigues A, et al. Nutritional status, biological maturation and cardiorespiratory fitness in Azorean youth aged 11-15 years. BMC Public Health. 2013;13:495, http://dx.doi.org/10.1186/1471-2458-13-495.
6. Gillison F, Cumming S, Standage M, Barnaby C, Katzmarzyk P. Assessing the impact of adjusting for maturity in weight status classification in a cross-sectional sample of UK children. BMJ Open. 2017;7:e015769, http://dx.doi.org/10.1136/bmjopen-2016-015769.
7. Gómez-Campos R, Arruda M, Hobold E, Abella CP, Camargo C, Martínez Salazar C, et al. Valoración de la maduración biológica: usos y aplicaciones en el ámbito escolar. Rev Andal Med Deporte. 2013;6:151–60.
8. Beunen GP, Rogol AD, Malina RM. Indicators of biological maturation and secular changes in biological maturation. Food Nutr Bull. 2006;27 Suppl. 4:S244–56, http://dx.doi.org/10.1177/15648265060274S508.
9. Malina RM, Rogol AD, Cumming SP, Coelho-e-Silva MJ, Figueiredo AJ. Biological maturation of youth athletes: assessment and implications. Br J Sports Med. 2015;49:852–9, http://dx.doi.org/10.1136/bjsports-2015-094623.
10. Mirwald RL, Baxter-Jones ADG, Bailey DA, Beunen GP. An assessment of maturity from anthropometric measurements. Med Sci Sports Exerc. 2002;34:689–94.
11. Moore SA, McKay HA, Macdonald H, Nettlefold L, Baxter-Jones AD, Cameron N. Enhancing a somatic maturity prediction model. Med Sci Sports Exerc. 2015;47:1755–64, http://dx.doi.org/10.1249/MSS.0000000000000588.
12. Malina RM. Top 10 research questions related to growth and maturation of relevance to physical activity, performance, and fitness. Res Q Exerc Sport. 2014;85:157–73, http://dx.doi.org/10.1080/02701367.2014.897592.
13. Leite Portella D, Arruda M, Gómez-Campos R, Checkin Portella G, Andruske CL, Cossio-Bolaños MA. Physical growth and biological maturation of children and adolescents: proposed reference curves. Ann Nutr Metab. 2017;70:329–37, http://dx.doi.org/10.1159/000475998.
14. Cumming SP, Lloyd RS, Oliver JL, Eisenmann JC, Malina RM. Biobanding in sport: applications to competition, talent identification, and strength and conditioning of youth athletes. Strength Cond J. 2017;39:34–47.
15. Meylan C, Cronin J, Oliver J, Hughes M. Talent identification in soccer: the role of maturity status on physiological and technical characteristics. Int J Sport Sci Coach. 2010;5:571–92, http://dx.doi.org/10.1260/1747-9541.5.4.571.

16. Kozieł SM, Malina RM. Modified maturity offset prediction equations: validation in independent longitudinal samples of boys and girls. Sports Med. 2018;48:221–36, http://dx.doi.org/10.1007/s40279-017-0750-y.
17. Preece MA, Baines MJ. A new family of mathematical models describing the human growth curve. Ann Human Biol. 1978;5:l–l24.
18. Tanner JM. Use and abuse of growth standards. Human Growth. 1985;3:95–109.
19. Ross WD, Marfell-Jones MJ. Kinanthropometry. In: MacDougall JD, Wenger HA, Geeny HJ, editors. Physiological testing of eliteathlete. London: Human Kinetics; 1991. p. 308–14, 223.
20. Tanner JM, Hayashi T, Preece MA, Cameron N. Increase in lenght of leg relative to trunk in Japanese Children and adults from 1957 to 1977: a comparison with British and Japanese Americans. Ann Hum Biol. 1982;9:411–23.
21. Santos C, Bustamante A, Katzmarzyk PT, Vasconcelos O, Garganta R, Freitas D, et al. Growth velocity curves and pubertal spurt parameters of Peruvian children and adolescents living at different altitudes. The Peruvian health and optimist growth study. Am J Hum Biol. 2019;31:e23301.
22. Datta Banik S, Salehabadi SM, Dickinson F. Preece-Baines model 1 to estimate height and knee height growth in boys and girls from Merida, Mexico. Food Nutr Bull. 2017;38:182–95.
23. Malina RM, Koziel SM. Validation of maturity offset in a longitudinal sample of Polish girls. J Sports Sci. 2014;32:1374–82, http://dx.doi.org/10.1080/02640414.2014.889846.
24. Fransen J, Bush S, Woodcock S, Novack A, Deprez D, Baxter Jones AD, et al. Improving the prediction of maturity from anthropometric variables using a maturity ratio. Pediatr Exerc Sci. 2018;30:296–307, http://dx.doi.org/10.1123/pes.2017-0009.
25. Myburgh GK, Cumming SP, Malina RM. Cross-sectional analysis investigating the concordance of maturity status classifications in elite Caucasian youth tennis players. Sports Med Open. 2019;5:27, http://dx.doi.org/10.1186/s40798-019-0198-8.
26. Cossio-Bolaños M, de Arruda M, Sulla Torres J, Urra Albornoz C, Gómez Campos R. Development of equations and proposed reference values to estimate body fat mass among Chilean children and adolescents. Arch Argent Pediatr. 2017;115:453–61, http://dx.doi.org/10.5546/aap.2017.eng.453.
27. Cossio-Bolaños M, Rubio-Gonzalez J, Luarte-Rocha C, Rivera-Portugal M, Urra-Albornoz C, Gomez-Campos R. Variables antropométricas, maduración somática y flujo espiratorio: determinantes de la masa libre de grasa en jóvenes nadadores. Retos. 2020;37:406–11.